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X-ray imaging system and learned model production method

Abstract

An X-ray imaging system is configured to acquire first and second images from a teacher X-ray image including an inspection target. Discrimination information to discriminate at least one of an area of the inspection target in the first and second images, and an area of a defect part is acquired. Machine learning for producing a learned model is performed by using input teacher data sets based on the first and second images, and output teacher data sets based on the discrimination information.

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References Cited

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
2022/070491	12/2021	WO	N/A

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS

(1) The related application number JP2022-132482, an X-ray imaging system and a learned model production method, Aug. 23, 2022, Hiroaki Tsushima, Ryuji Sawada upon which this patent application is based are hereby incorporated by reference.

FIELD

(2) The present invention relates to an X-ray imaging system and a learned model production method, and particularly to an X-ray imaging system and learned model production method capable of producing a learned model.

BACKGROUND

(3) Conventionally, an apparatus producing a learned model is known. Such an apparatus is disclosed in International Publication No. WO 2022-070491, for example.

(4) The above International Publication No. WO 2022-070491 discloses an apparatus (image analyzing device) estimating an area or position of an analysis object in an analysis object image. In the above International Publication No. WO 2022-070491, image analysis using machine learning is used in this estimation. The image analyzing device disclosed in the above International Publication No. WO 2022-070491 produces a learned model performing machine learning using an analysis object image and a label image corresponding to the analysis object image. Analysis is then performed by using the produced learned model. The image analyzing device disclosed in the above International Publication No. WO 2022-070491 entirely applies binarization processing to the analysis object image as an original image so as to convert boundary parts of the analysis object in the image to numerical values, and combines the original image with the processing-applied image in which the boundary parts are converted to numerical values, whereby acquiring the label image.

(5) Although not stated in the above International Publication No. WO 2022-070491, to produce teacher data (label images) used for machine learning, workers (operators) manually select areas in

original images (analysis object images) to apply processing to the images in some cases. In such cases, as in the image analyzing device disclosed in the above International Publication No. WO 2022-070491, if operators manually entirely apply processing to a number of original images to produce teacher data, such teacher data production is a burden on the operators. For this reason, in a case in which a learned model to detect at least one of an area of an analysis object (inspection target) and an area of a defect part included in the inspection target is produced, it is desired to reduce such a burden on operators in teacher data production.

SUMMARY

(6) The present invention is intended to solve the above problems, and one object of the present invention is to provide an X-ray imaging system and a learned model production method capable of reducing a burden on operators in teacher data production in a case in which a learned model to detect at least one of an area of an analysis object (inspection target) and an area of a defect part included in the inspection target is produced.

(7) In order to attain the aforementioned object, an X-ray imaging system according to a first aspect of the present invention includes an X-ray emitter configured to emit X-rays to an inspection target having a regular arrangement; an X-ray detector configured to detect the X-rays emitted from the X-ray emitter; an image generator configured to generate an X-ray image based on the X-rays that are detected by the X-ray detector; and a model producer configured to produce a learned model for analysis of the X-ray image generated by the image generator, wherein the model producer includes a cut-out image acquirer configured to acquire a first image that is cut out corresponding to a first part from a teacher X-ray image including the inspection target having a regular arrangement, and a second image that is cut out corresponding to a second part different from the first part from the teacher X-ray image; a discrimination information acquirer configured to acquire discrimination information to discriminate at least one of an area of the inspection target in the first and second images, and an area of a defect part included in the inspection target in the first and second images; and a learning performer configured to perform machine learning for producing a learned model by using input teacher data sets based on the first and second images, and output teacher data sets based on the discrimination information.

(8) A learned model production method according to a second aspect of the present invention includes a step of acquiring a first image that is cut out corresponding to a first part from a teacher X-ray image corresponding to an X-ray image generated by irradiating an inspection target having a regular arrangement with X-rays, and a second image that is cut out corresponding to a second part different from the first part from the teacher X-ray image; a step of acquiring discrimination information to discriminate at least one of an area of the inspection target in the first and second images, and an area of a defect part included in the inspection target in the first and second images; and a step of performing machine learning for producing a learned model for analysis of the X-ray image by using input teacher data sets based on the first and second images, and output teacher data sets based on the discrimination information.

(9) In the X-ray imaging system according to the first aspect and the learned model production method according to the second aspect, a first image that is cut out corresponding to a first part from a teacher X-ray image including the inspection target having a regular arrangement, and a second image that is cut out corresponding to a second part different from the first part from the teacher X-ray image are acquired. Discrimination information to discriminate at least one of an area of the inspection target in the first and second images, and an area of a defect part included in the inspection target is acquired. Accordingly, the acquired discrimination information to discriminate the first image of the teacher X-ray image with the first part being cut out from the teacher X-ray image, and the second image of the teacher X-ray image with the second part being cut out from the teacher X-ray image can reduce a burden on operators of acquiring discrimination information as compared with a case in which operators acquire discrimination information corresponding to the entire teacher X-ray image. As a result, because a burden on operators of

acquiring output teacher data to perform machine learning can be reduced, in a case in which a learned model to detect at least one of an area of an inspection target and an area of the defect part included in the inspection target is produced, it is possible to reduce such a burden on operators in teacher data production. Also, in a case in which X-rays are emitted by a point source of light in X-ray imaging, in a generated X-ray image, a central image in an emission center of X-rays and peripheral images in peripheral parts away from the emission center are images corresponding to different incident angle directions of X-rays different from each other. Contrary to this, in the present invention, a first image that is cut out corresponding to a first part from a teacher X-ray image including the inspection target having a regular arrangement, and a second image that is cut out corresponding to a second part different from the first part from the teacher X-ray image are acquired. Because the inspection target in the teacher X-ray image is arranged in a regular arrangement, the images of the inspection target in the first and second images can be projection images corresponding to a structure having a common arrangement relation. Accordingly, the first and second parts including images corresponding to different angle directions of X-rays incident on a structure having a common arrangement relation can be cut out from the teacher X-ray image by acquiring the first and second images. For this reason, even in a case in which not the entire teacher X-ray image but images that are cut out corresponding to parts of the teacher X-ray image are used, teacher data can be acquired to properly represent the entire projection image of the teacher X-ray image, and as a result it is possible to prevent accuracy reduction of discrimination result by the learned model generated by machine learning. Therefore, a burden on operators in teacher data production for producing a learned model can be reduced by using the first and second imaged cut out from the teacher X-ray image while accuracy reduction of discrimination result by the learned model generated by machine learning is prevented.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a block diagram showing the overall configuration of an X-ray imaging system according to one embodiment of the present invention.
(2) FIG. **2** is a schematic diagram showing arrangement of a subject including solder balls.
(3) FIG. **3** is a diagram showing an exemplary X-ray image.
(4) FIG. **4** is a block diagram illustrating the functional configuration of a controller.
(5) FIG. **5** is a diagram illustrating inference by using a learned model.
(6) FIG. **6** is a diagram illustrating an exemplary discrimination result image provided by the inference using the learned model.
(7) FIG. **7** is a diagram illustrating target area specification in a teacher X-ray image.
(8) FIG. **8** is a diagram illustrating range specification used for acquisition of central and end images in the teacher X-ray image.
(9) FIG. **9** is a diagram illustrating range specification about a background part in the teacher X-ray image.
(10) FIG. **10** is a diagram illustrating acquisition of discrimination images corresponding to the central, end and background images.
(11) FIG. **11** is a diagram illustrating generation of input teacher data based on the central, end and background images.
(12) FIG. **12** is a diagram illustrating generation of output teacher data based on the discrimination images.
(13) FIG. **13** is a diagram (flowchart) illustrating an X-ray image analysis method using a learned model.
(14) FIG. **14** is a diagram (flowchart) illustrating a learned model production method.

DETAILED DESCRIPTION

(15) Embodiments embodying the present invention are hereinafter described on the basis of the drawings.

(16) (Overall Configuration of X-Ray Imaging System)

(17) An X-ray imaging system **100** according to one embodiment of the present invention is now described with reference to FIGS. **1** to **12**.

(18) As shown in FIG. **1**, the X-ray imaging system **100** according to the embodiment can provide an internal image of a subject **101** by detecting X-rays that pass through the subject **101**. For example, the X-ray imaging system **100** can be used for non-destructive inspection applications to provide an internal image of the subject **101** as an object.

(19) As shown in FIG. **2**, the subject **101** is an electronic device including a substrate **102**. Electronic components **103** are mounted on both surfaces of the substrate **102**. The electronic components **103** are electrically connected to the substrate **102** by a plurality of solder balls **104** (bumps). The plurality of solder balls **104** are arranged in a regular arrangement. Specifically, the plurality of solder balls **104** are regularly arranged in a grid arrangement on the substrate **102**. In other words, the electronic components **103** are connected to the substrate **102** by using a BGA (Ball Grid Array). A plurality of solder balls **104** are arranged on each of front and back surfaces of the substrate **102**. For example, in the subject **101**, thirty nine solder balls **104** are arranged in a grip shape of three rows and thirteen columns on each of the front and back surfaces of the substrate **102**. The solder balls **104** on the front surface of the substrate **102** and the solder balls **104** on the back surface overlap each other as viewed in a direction orthogonal to the front surface of the substrate **102**. For example, the electronic components **103** include an electronic circuit, such as IC (integrated circuit). The X-ray imaging system **100** can perform non-destructive inspection for a defect such as a void (hole) in any of the solder balls **104**, and solder bridging. Also, another electronic component **105**, such as surface-mount type resistor or capacitor is mounted on the substrate **102** in addition to the electronic components **103**. The plurality of solder balls **104** is an example of an “inspection target” or a “plurality of solder material pieces”.

(20) As shown in FIG. **1**, the X-ray imaging system **100** includes a fluoroscopic device **10** and an analysis device **20**. The fluoroscopic device **10** can generate an X-ray image **30** (see FIG. **3**) by capturing an X-ray image of the subject **101**. The analysis device **20** can apply analysis processing to the generated X-ray image **30**. The analysis device **20** can apply analysis processing to the generated X-ray image **30**.

(21) The fluoroscopic device **10** includes an X-ray emitter **11**, an X-ray detector **12** and an image generator **13**. The X-ray emitter **11** is configured to emit X-rays to the subject **101** including the plurality of solder balls **104**. The X-ray emitter **11** includes an X-ray tube configured to emit X-rays when electric power is supplied from a power supply (not shown). The X-ray detector **12** is configured to detect X-rays emitted from the X-ray emitter **11**. The X-ray detector **12** is configured to provide electrical signals in accordance with the detected X-rays. The X-ray detector **12** includes a flat panel detector (FPD) as a detector for detecting X-rays, for example. The X-ray emitter **11** and the X-ray detector **12** are arranged in a housing (not shown) of the fluoroscopic device **10**.

(22) As shown in FIG. **3**, the image generator **13** is configured to generate the X-ray image **30** based on X-rays detected by the X-ray detector **12**. The image generator **13** is a computer including a processor such as CPU (Central Processing Unit) and a storage device for storing information. The image generator **13** is configured to control operations of parts of the fluoroscopic device **10**. For example, the image generator **13** can control the power supply (not shown) whereby controlling emission of X-rays emitted by the X-ray emitter **11**. Also, the image generator **13** can provide the generated X-ray image **30** to the analysis device **20**.

(23) The X-ray image **30** includes the plurality of solder balls **104**, which are arranged having a regular arrangement, such as a grid arrangement. Because a plurality of solder balls **104** are arranged on each of the both surfaces of the substrate **102** in the subject **101**, the X-ray image **30**

includes overlap parts in which solder balls **104** overlap each other. Also, because the X-ray emitter **11** is a point source of light, the central and end parts of the X-ray image **30** have different overlapping degrees of solder balls **104** different from each other.
(24) As shown in FIG. **1**, the analysis device **20** includes a controller **21** and a storage **22**. For example, the analysis device **20** is a personal computer that is connected to and can communicate with the fluoroscopic device **10**. The controller **21** includes a CPU, a read only memory (ROM), a random access memory (RAM), etc. The controller **21** can include a processor such as a graphics processing unit (GPU) or a field-programmable gate array (FPGA) configured for image processing. The controller **21** is an example of a "model producer" in the claims.
(25) The storage **22** is configured to store various programs to be executed by the controller **21**, and parameters. The storage **22** includes an HDD (Hard Disk Drive) or a nonvolatile memory such as SSD (Solid State Drive), for example.
(26) A display **23** and an input device (user input acceptor) **24** are connected to the analysis device **20**. The display **23** includes an LCD monitor, for example. The display **23** is configured to display images and text information based on the control by the controller **21**. The input device **24** is configured to accept user inputs from users (user input instructions). The input device **24** includes a keyboard and a pointing device, such as a computer mouse, for example. The input device **24** can provide the user input signals in accordance with the accepted user inputs to the controller **21**.
(27) Also, as shown in FIG. **4**, the controller **21** includes an analyzer **41**, a display processor **42**, a cut-out image acquirer **43**, a discrimination information acquirer **44**, a teacher data producer **45** and a learning performer **46**. The controller **21** can serve as the analyzer **41**, the display processor **42**, the cut-out image acquirer **43**, the discrimination information acquirer **44**, the teacher data producer **45** and the learning performer **46** by executing various programs (software) stored in the storage **22**. In other words, the analyzer **41**, the display processor **42**, the cut-out image acquirer **43**, the discrimination information acquirer **44**, the teacher data producer **45** and the learning performer **46** in FIG. **4** are represented as functional software blocks. The present invention is not limited to this, but some of or all of the analyzer **41**, the display processor **42**, the cut-out image acquirer **43**, the discrimination information acquirer **44**, the teacher data producer **45** and the learning performer **46** can be constructed of a dedicated hardware circuit.
(28) (Analysis of X-Ray Image by Analysis Device)
(29) As shown in FIG. **5**, the analyzer **41** is configured for analysis of the X-ray image **30** by using a learned model **50**. Specifically, the analysis device **20** uses the learned model **50** to discriminate areas of the solder balls **104** whereby acquiring a discrimination result image **31** as a discrimination result (inference result) by the learned model **50** from the X-ray image **30**. The learned model **50** can be produced by the controller **21** of the analysis device **20** and stored in the storage **22**. The production of the learned model **50** will be discussed in detail later.
(30) As shown in FIG. **6**, the discrimination result image **31** is a label image including three types of discriminated areas of overlapping parts each of which is a part where the solder balls **104** on the both surfaces of the substrate **102** overlap each other, non-overlapping parts each of which is a part included only in only corresponding one of the solder balls **104** but excluded from the overlapping part (a part of one of the solder balls **104** that does not overlap another), and a background part where any of the solder balls **104** is not included. The overlapping parts where the solder balls **104** overlap each other, the non-overlapping parts, which are included in only their corresponding one of the solder balls **104** but excluded from the overlapping part, and the background part where no solder ball **104** exists are represented by solid gray, white, and black, respectively, in the discrimination result image **31**. Note that the gray is represented by hatching in FIG. **6**.
(31) The analyzer **41** can determine based on the areas discriminated in the discrimination result image **31** whether any defect occurs in the solder balls **104** included in the X-ray image **30**. The analyzer **41** detects the areas of the solder balls **104** in the X-ray image **30** based on the discrimination result image **31**, and detects an area and a shape of each solder ball **104**, for

example. The analyzer **41** then determines based on the detected area and shape of each solder ball **104** whether any defect such as void (hole), poor wetting, solder bridging and spattering occurs in the solder ball **104**.

(32) The display processor **42** controls function of displaying images and text information on the display **23**. For example, the X-ray image **30** and a teacher X-ray image **60** (see FIG. **7**) described below can be displayed on the display **23** by the display processor **42**. Also, the display processor **42** can discriminatively display a defect part that is determined in the X-ray image **30** as analysis result analyzed by the analyzer **41** on the display **23**.

(33) <Production of Learned Model>

(34) As shown in FIG. **5**, in this present embodiment, the controller **21** is configured to produce the learned model **50** for analysis of the X-ray image **30** generated by the image generator **13**. The learned model **50** is produced by machine learning using data sets of input and output teacher data **30***t* and **31***t*. The input teacher data sets **30***t* are produced based on the teacher X-ray image **60** (see FIG. **7**). The teacher X-ray image **60** is generated by the fluoroscopic device **10** similar to the X-ray image **30** to be analyzed.

(35) For example, the X-ray imaging system **100** inspects a plurality of subjects **101** that have a common structure including the plurality of solder balls **104**. To address this inspection, the X-ray imaging system **100** irradiates some of the subjects **101** of a plurality of subjects **101** with X-rays, and generates a plurality of X-ray images **30** whereby acquiring the X-ray images **30** as a plurality of teacher X-ray images **60**. Subsequently, the learned model **50** is produced based on the acquired plurality of teacher X-ray images **60**. To address this inspection, it is determined whether any defect occurs in the solder ball **104** based on X-ray images **30** of the other subjects **101** of the plurality of subjects **101** that are generated by irradiation of the other subjects **101** with X-rays. That is, the X-ray image **30** to be analyzed, and the teacher X-ray image **60** for producing the learned model **50** are images including subjects **101** (solder balls **104**) having the same structure as each other.

(36) As shown in FIG. **7**, the cut-out image acquirer **43** is configured to specifies a target area **60***a* including the plurality of solder balls **104** in the teacher X-ray image **60**, which is acquired to produce the learned model **50**. Specifically, the user input acceptor **24** accepts an area-specifying instruction that specifies the target area **60***a* in the teacher X-ray image **60**. An operator (worker) will entirely see the teacher X-ray image **60** on display **23** displayed by the display processor **42**, and provide the user input acceptor **24** with an area-specifying instruction that specifies the target area **60***a*. The cut-out image acquirer **43** acquires the target area **60***a* in the teacher X-ray image **60** specified by the area-specifying instruction provided by using the user input acceptor **24**. At this time, the display **23** displays a dotted frame that indicates a range (boundary) of the target area **60***a* and is superimposed on the teacher X-ray image **60** as indication indicating the range of the specified target area **60***a*.

(37) Subsequently, in response to the area-specifying instruction provided by using the user input acceptor **24**, the cut-out image acquirer **43** acquires a central image **61***b* (see FIG. **10**) that is cut out corresponding to a part **60***b* including a central part of the target area **60***a*, and two end images **61***c* and **61***d* (see FIG. **10**) that are cut out corresponding to parts **60***c* and **60***d* including the end parts, which are different from the part **60***b* of the target area **60***a*, from the teacher X-ray image **60**, which includes the plurality of solder balls **104** arranged having a regular arrangement, as shown in FIG. **8**. The part **60***b* is an example of a “first part” in the claims. The parts **60***c* and **60***d* are an example of a “second part” in the claims. The central image **61***b* is an example of a “first image” in the claims. The end images **61***c* and **61***d* are an example of a “second image” in the claims.

(38) Specifically, the cut-out image acquirer automatically specifies a range of the part **60***b*, which is a cut-out range of the central image **61***b* from the teacher X-ray image **60**, and a range of the parts **60***c* and **60***d*, which are cut-out ranges of end images **61***c* and **61***d* from the teacher X-ray image **60**, based on the target area **60***a* in the teacher X-ray image **60** specified by the area-specifying instruction accepted by the user input acceptor **24**. For example, the cut-out image

acquirer **43** specifies an area that expands from a center in the specified target area **60***a* in a vertical size 120% of the target area **60***a* and has a horizontal size 30% of the target area **60***a* as a range of the part **60***b*. Also, the cut-out image acquirer **43** specifies an area that expands from a left edge of the target area **60***a* in a horizontal size 10% of the target area **60***a* and has a vertical size 120% of the target area **60***a* as a range of the part **60***c*. Also, the cut-out image acquirer **43** specifies an area that expands from a right edge of the target area **60***a* in a horizontal size 10% of the target area **60***a* and has a vertical size 120% of the target area **60***a* as a range of the part **60***d*. The cut-out image acquirer **43** assigns a common size to the parts **60***c* and **60***d*. For example, sizes (ratios to the target area **60***a*) in the ranges of the parts **60***b*, **60***c* and **60***d* are previously specified.

(39) In addition, the display **23** visually displays an indication indicating a range of the part **60***b* to be cut out from the teacher X-ray image **60** and indications indicating ranges of the parts **60***c* and **60***d* to be cut out from the teacher X-ray image. For example, the display **23** displays dotted frames that are superimposed on the teacher X-ray image **60** as indication indicating the ranges of the parts **60***b*, **60***c* and **60***d* similar to the target area **60***a*. Also, the cut-out image acquirer **43** specifies the ranges of the first and second parts **60***b*, **60***c* and **60***d* to be cut out from the teacher X-ray image **60** based on the user input instruction accepted that changes ranges of the parts **60***b*, **60***c* and **60***d* by the user input acceptor **24**. In other words, the cut-out image acquirer **43** is configured to be able to change the previously specified ranges of the parts **60***b*, **60***c* and **60***d*. For example, the user input acceptor **24** accepts a range-specifying instruction that specifies (changes) ranges of the parts **60***b*, **60***c* and **60***d* when the indication indicating the ranges of the parts **60***b*, **60***c* and **60***d* is displayed together with the teacher X-ray image **60** on the display **23**. When any of the ranges is changed, the display processor **42** will visually display the changed range on the display **23**.

(40) In this case, the cut-out image acquirer **43** specifies the ranges of the parts **60***b*, **60***c* and **60***d* which have a size not smaller than a predetermined threshold(s) based on the user input instruction (range-specifying instruction) that specifies (changes) ranges of the parts **60***b*, **60***c* and **60***d* accepted by the user input acceptor **24**. The storage **22** previously stores the predetermined threshold. For example, the predetermined threshold is specified so as to prevent a horizontal size (length) of a range of the part **60***b* as the range of the central image **61***b* from becoming smaller than 20% of the target area **60***a*. Also, the predetermined threshold is specified so as to prevent a horizontal size (length) of a range of the part **60***c* or **60***d* as the range of the end image **61***c* or **61***d* from becoming smaller than 10% of the target area **60***a*. Also, the predetermined threshold is specified so as to prevent a vertical size (length) of a range of the part **60***b*, **60***c* or **60***d* from becoming smaller than 120% of the target area **60***a*. In other words, the cut-out image acquirer **43** is configured to prevent the central image **61***b* and the end images **61***c* and **61***d* to be cut out from becoming smaller than the predetermined size.

(41) For example, the predetermined threshold for the horizontal size of each of the ranges of the parts **60***b*, **60***c* and **60***d* is greater than at least one solder ball **104** size in the parts **60***b*, **60***c* and **60***d*. In other words, the horizontal size of each of the ranges of the parts **60***b*, **60***c* and **60***d* can be specified greater than at least one cycle length in cycle lengths of the regular arrangement of the plurality of solder balls **104**, which are regularly arranged.

(42) Also, after the ranges of the part **60***b*, part **60***c* and part **60***d* are specified, the cut-out image acquirer **43** specifies a range of the background image **61***e* (see FIG. **10**) corresponding to the background part **60***e* where no solder ball **104** exists to be cut out from the teacher X-ray image **60** based on the user input instruction accepted by the user input acceptor **24** as shown in FIG. **9**. For example, the user input acceptor **24** accepts a range-specifying instruction that specifies the range of the background part **60***e* with the teacher X-ray image **60** being entirely displayed by the display processor **42**. At this time, the ranges of the parts **60***b*, **60***c* and **60***d*, which have been specified, are discriminatively indicated on the displayed teacher X-ray image **60**. For example, the ranges of the parts **60***b*, **60***c* and **60***d* are represented by solid gray. Also, the display **23** displays a dotted frame that indicates the range of the background part **60***e* and is superimposed on the teacher X-ray image

60 as indication indicating the range of the background part **60***e*. The background part **60***e* does not include any solder ball **104** but includes the substrate **102**, the electronic component **105**, etc., for example.

(43) The cut-out image acquirer **43** acquires the central image **61***b* corresponding to the specified range of the part **60***b*, the end images **61***c* and **61***d* corresponding to the specified ranges of the parts **60***c* and **60***d*, and the background images **61***e* corresponding to the specified range of the background part **60***e* by cutting out them from the teacher X-ray image **60** in accordance with the range-specifying instructions.

(44) In this embodiment, in a case in which the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* are acquired from a plurality of teacher X-ray images **60**, the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* corresponding to common ranges in each teacher X-ray image **60** are acquired. Specifically, the user input acceptor **24** is configured to accept range-specifying instructions that specify the range of the part **60***b*, the ranges of the parts **60***c* and **60***d*, and the range of the background part **60***e* in one teacher X-ray image among the plurality of teacher X-ray images **60**. The cut-out image acquirer **43** is configured to acquire a plurality of the central image **61***b* corresponding to a common range of the part **60***b*, which is specified in accordance with the range-specifying instruction in the one teacher X-ray image **60**, cut out from the plurality of teacher X-ray images **60**, a plurality of the end images **61***c* and **61***d* corresponding to a common ranges of the parts **60***c* and **60***d*, which is specified in accordance with the range-specifying instructions in the one teacher X-ray image **60**, cut out from the plurality of teacher X-ray images **60**, and a plurality of the background image **61***e* corresponding to a common range of the background part **60***e*, which is specified in accordance with the range-specifying instruction in the one teacher X-ray image **60**, cut out from the plurality of teacher X-ray images **60**.

(45) As shown in FIG. **10**, the discrimination information acquirer **44** acquires discrimination information to discriminate areas of the solder balls **104** in the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* in response to an input instruction provided to the user input acceptor **24**. Specifically, the discrimination information acquirer **44** acquires a discrimination image **62***b*, discrimination images **62***c* and **62***d*, and a discrimination image **62***e* which discriminate areas of the solder balls **104** in the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e*, respectively, as the discrimination information in response to the input instruction provided to the user input acceptor **24**.

(46) Specifically, the display processor **42** displays the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* acquired by the cut-out image acquirer **43** on the display **23**. Operators (workers) can see the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* displayed and classify (label) parts corresponding to the solder balls **104** included in the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* into their corresponding colors. For example, an operator classifies the overlapping parts where the solder balls **104** on the both surfaces of substrate **102** overlap each other, the non-overlapping parts, which are included in only their corresponding one of the solder balls **104** but excluded from the overlapping part, and the part where no solder ball **104** exists into solid gray, white, and black, respectively, in the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e*, so that the discrimination information acquirer **44** can acquire the discrimination images **62***b* to **62***e*. Because the background image **61***e* will not include any solder ball **104**, the black discrimination image **62***e* can be automatically entirely acquired.

(47) As shown in FIG. **11**, the teacher data producer **45** is configured to produce a plurality of input teacher data sets **30***t* based on the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* acquired by the cut-out image acquirer **43**. Specifically, the teacher data producer **45** is configured to adjust the plurality of input teacher data sets **30***t* to a common size by using at least one of an inverse alignment in which a plurality of central images **61***b*, which are

produced by reproducing the central image **61***b*, are inversely placed in alignment, and an inverse alignment in which a plurality of end images **61***c* and **61***d*, which are produced by reproducing the end images **61***c* and **61***d*, are inversely placed in alignment. Also, in a case in which input teacher data **30***t* is produced based on the background image **61***e*, the teacher data producer **45** also produces the input teacher data sets **30***t* having a common size by using an inverse alignment in which a plurality of background images **61***e*, which are produced by reproducing the background image **61***e*, are inversely placed in alignment.

(48) For example, the teacher data producer **45** acquires as a vertical size of the input teacher data sets **30***t* a vertical size of the image that has the largest vertical size from the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* acquired by the cut-out image acquirer **43**. Also, the teacher data producer **45** acquires as a horizontal size of the input teacher data sets **30***t* a horizontal size of the image that has the largest horizontal size from the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* acquired by the cut-out image acquirer **43**.

(49) Subsequently, the teacher data producer **45** reproduces the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* that have the same vertical and horizontal sizes as the acquired input teacher data sets **30***t*, and inversely places the reproduced images in alignment (inverse alignment). In an example of FIG. **11**, among the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e*, the central image **61***b* has the largest vertical and horizontal lengths. As a result, the size of the input teacher data sets **30***t* agrees with the size of central image **61***b*. The teacher data producer **45** adjusts sizes of the end images **61***c* and **61***d*, and the background image **61***e* to a common size with (same size as) the central image **61***b*. In this adjustment, when horizontal lengths of sizes of the end images **61***c* and **61***d*, and the background image **61***e* are increased, the teacher data producer **45** places adjacent to the end images **61***c* and **61***d*, and the background image **61***e* on the right and left sides the end images **61***c* and **61***d*, and the background image **61***e* that are produced by reproducing them and horizontally inverted. For example, if a horizontal size difference between the common horizontal length and the horizontal length of the end image or the background image is not an integral multiple of the horizontal length of the end image or the background image, images that are not a fully-reproduced image are placed adjacent to the end image or the background image on the right and left sides. Also, if a plurality of reproduced images are arranged adjacent to each other, the reproduced images adjacent to each other are inversely placed relative to each other. In other words, the end image **61***c* or **61***d*, or the background image **61***e* that is not inverted and the end image **61***c* or **61***d*, or the background image **61***e* that is inverted are alternately arranged. Also, if a vertical length of an image increased, the teacher data producer **45** can reproduce the image, and can similarly place reproduced images, which are reproduced from the image, in the alternate arrangement in which non-inverted and inverted reproduced images are alternately arranged.

(50) As shown in FIG. **12**, the teacher data producer **45** is configured to produce a plurality of output teacher data sets **31***t* based on the discrimination images **62***b*, **62***c*, **62***d* and **62***e*. The teacher data producer **45** applies processing similar to the acquisition of the input teacher data sets **30***t* to the discrimination images **62***b* to **62***e*. In other words, similar to the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* corresponding to the discrimination image **62***b* to **62***e*, the teacher data producer **45** produces the output teacher data sets **31***t* having a common size by using an inverse alignment in which a plurality of the discrimination images **62***b* to **62***e*, which are produced by reproducing them, are inversely placed in alignment. Because the discrimination image **62***e* corresponding to the background image **61***e* is an image that is entirely represented by solid black, the output teacher data sets **31***t* that is entirely represented by solid black can be acquired in accordance with a size of the output teacher data sets **31***t* that is acquired without the aforementioned inverse alignment processing. As a result, the teacher data producer **45** can produce a plurality of input teacher data sets **30***t* and a plurality of output teacher data sets **31***t* which are images having the common size.

(51) As shown in FIG. **5**, the learning performer **46** is configured to perform machine learning for producing the learned model **50** by using the input teacher data sets **30***t* based on the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e*, and the output teacher data sets **31***t* based on the discrimination images **62***b*, **62***c*, **62***d* and **62***e* corresponding to the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e*. In other words, the learning performer **46** uses a plurality of input teacher data sets **30***t* and a plurality of output teacher data sets **31***t* produced by the teacher data producer **45** as data sets to perform machine learning for producing the learned model **50**. The learned model **50** is produced by machine learning using deep learning. For example, the learning performer **46** generates the learned model **50** by using machine learning based on U-Net, which is one type of Fully Convolutional Network (FCN). The learned model **50** is produced by leaning to apply image conversion (image reconstruction) to pixels in the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e*, which are inputs, so as to classify the overlapping parts where the solder balls **104** on the both surfaces overlap each other, the non-overlapping parts, which are included in only their corresponding one of the solder balls **104** but excluded from the overlapping part, and the part where no solder ball **104** exists into solid gray, white, and black, respectively.
(52) (X-Ray Image Analysis Method of the Embodiment)
(53) An X-ray image analysis method according to this embodiment is now described with reference to FIG. **13**. Control processing in steps **201** to **204** is performed by executing a program by means of the controller **21**.
(54) A plurality of teacher X-ray images **60** for producing the learned model **50** is first acquired in step **201**. Subsequently, the learned model **50** is produced based on the plurality of teacher X-ray images **60** in step **202**. The produced learned model **50** is stored into the storage **22**. Subsequently, a plurality of X-ray images **30** as analysis targets are acquired in step **203**. The plurality of X-ray images **30** as analysis targets are generated based on X-ray imaging in which X-ray images of a plurality of subjects **101** as inspection targets are captured. Subsequently, analysis using the produced learned model **50** in step **202** is applied to the acquired plurality of X-ray images **30** in step **204**. In the analysis using the learned model **50**, a plurality of discrimination result images **31** are acquired from a plurality of X-ray images **30** as analysis targets. Subsequently, it is determined based on the acquired plurality of discrimination result images **31** whether any defect occurs in a plurality of solder balls **104** included in the subject **101**. Any one of the acquisition of the plurality of teacher X-ray images **60** in step **201**, and the acquisition of the plurality of X-ray images **30** in step **203** can be executed prior to another. Also, a plurality of teacher X-ray images **60** can be acquired from a plurality of X-ray images **30** acquired.
(55) (Learned Model Production Method)
(56) A learned model production method according to this embodiment is now described with reference to FIG. **14**. Control processing in steps **301** to **309** represents the control processing of production of the learned model **50** in step **202** of FIG. **13**. Control processing in steps **301** to **309** is performed by executing the program by means of the controller **21**.
(57) A target area **60***a* is first specified in one teacher X-ray image **60** among the acquired plurality of teacher X-ray images **60** in step **301**. The target area **60***a* is specified in accordance with an area-specifying instruction as an input instruction through the user input acceptor **24**.
(58) Subsequently, ranges of the parts **60***b*, **60***c* and **60***d* to be cut out from the one teacher X-ray image **60** are automatically specified based on the specified target area **60***a* in step **302**.
(59) Subsequently, it is determined whether a range-specifying instruction as an input instruction that changes (specifies) a range of any of the parts **60***b*, **60***c* and **60***d* is accepted in step **303**. If it is determined that the range-specifying instruction is accepted, the procedure goes to step **304**. If it is determined that no range-specifying instruction is accepted, the procedure goes to step **305**.
(60) Subsequently, ranges of the parts **60***b*, **60***c* and **60***d* are newly specified in accordance with the range-specifying instruction in step **304**. In this range specification, the ranges of the parts **60***b*, **60***c*

and **60***d* are specified so as to have a size not smaller than a predetermined threshold. In other words, any instruction that specifies a range smaller than the predetermined threshold is not accepted. Subsequently, the procedure goes to step **305**.
(61) A background part **60***e* is specified in accordance with an input instruction through the user input acceptor **24** in step **305**. The step **305** for specifying the background part **60***e* can be omitted.
(62) Subsequently, the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* are acquired in step **306**. Specifically, the central image **61***b* obtained by cutting out the part **60***b* from the teacher X-ray image **60**, which corresponds to the X-ray image **30** generated by irradiating the plurality of solder balls **104** having a regular arrangement with X-rays, the end images **61***c* and **61***d* that are obtained by cutting out the part **60***c* and **60***d* different from the part **60***b* from the teacher X-ray image, and the background image **61***e* that is obtained by cutting out the background part **60***e* from the teacher X-ray image are acquired. Also, in accordance with the ranges of the parts **60***b*, **60***c* and **60***d* specified in step **302** or **304**, and the background part **60***e* specified in step **305**, common ranges of the central images **61***b*, common ranges of the end images **61***c* and **61***d*, and common ranges of the background images **61***e* are collectively acquired from the plurality of teacher X-ray images **60**.
(63) Subsequently, discrimination information to discriminate areas of the solder balls **104** in the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e* are acquired in response to an input instruction provided to the user input acceptor **24** in step **307**. Specifically, the discrimination image **62***b*, the discrimination images **62***c* and **62***d*, and the discrimination image **62***e*, which correspond to the central image **61***b*, the end images **61***c* and **61***d*, and the background image **61***e*, respectively, are acquired in response to the input instruction provided to the user input acceptor **24**.
(64) Subsequently, the input teacher data sets **30***t* and the output teacher data sets **31***t* are produced in step **308**. Specifically, based on the central image **61***b* and the end images **61***c* and **61***d*, and the background image **61***e* that are acquired in step **306**, the central image **61***b* and the end images **61***c* and **61***d*, and the background image **61***e* are reproduced and the reproduced images adjacent to each other are inversely placed relative to each other so that the plurality of input teacher data sets **30***t* as images having a common size are produced. Also, based on discrimination images **62***b*, **62***c*, **62***d* and **62***e* acquired in step **307**, the discrimination images **62***b* to **62***e* are reproduced and the reproduced images adjacent to each other are inversely placed relative to each other so that the plurality of output teacher data sets **31***t* as images having a common size are produced.
(65) Subsequently, machine learning for producing the learned model **50** is performed in step **309**. Specifically, machine learning using deep learning for producing the learned model **50** for analyzing the X-ray images **30** is performed by using the plurality of input teacher data sets **30***t* produced based on the central image **61***b* and the end images **61***c* and **61***d*, and the background image **61***e* in step **308**, and the plurality of output teacher data sets **31***t* produced based on the discrimination images **62***b* to **62***e* in step **308**.
Advantages of the Embodiment
(66) In this embodiment, the following advantages are obtained.
(67) In this embodiment, as discussed above, the X-ray imaging system **100** can acquire a central image **61***b* (first image) that is cut out corresponding to a part **60***b* (first part) from a teacher X-ray image **60** including solder balls **104** (inspection targets) having a regular arrangement, and end images **61***c* and **61***d* (second images) that are cut out corresponding to parts **60***c* and **60***d* (second parts) different from the part **60***b* from the teacher X-ray image. Discrimination images **62***b* to **62***d* (discrimination information) to discriminate areas of the solder balls **104** in the central image **61***b*, the end images **61***c* and **61***d* are acquired. Accordingly, the acquired discrimination images **62***b* to **62***d* to discriminate the central image **61***b* of the teacher X-ray image **60** with the part **60***b* being cut out from the teacher X-ray image, and the end images **61***c* and **61***d* of the teacher X-ray image with the parts **60***c* and **60***d* being cut out from the teacher X-ray image can reduce a burden on operators

of acquiring the discrimination images **62**_b_ to **62**_d_ as compared with a case in which operators acquire the discrimination images **62**_b_ to **62**_d_ corresponding to the entire teacher X-ray image **60**. As a result, because a burden on operators of acquiring output teacher data **31**_t_ to perform machine learning can be reduced, when a learned model **50** to detect areas of the solder balls **104** is produced, it is possible to reduce such a burden on operators in teacher data production. Also, in a case in which X-rays are emitted by a point source of light in X-ray imaging, in a generated X-ray image **30**, a central image in an emission center of X-rays and peripheral images in peripheral parts away from the emission center are images corresponding to different incident angle directions of X-rays different from each other. To address this, in this embodiment, the central image **61**_b_, which is cut out corresponding to the part **60**_b_ from the teacher X-ray image **60** including the solder balls **104** having a regular arrangement, and the end images **61**_c_ and **61**_d_, which are cut out corresponding to the parts **60**_c_ and **60**_d_ different from the part **60**_b_ from the teacher X-ray image, are acquired. Because the solder balls **104** in the teacher X-ray image **60** are arranged in a regular arrangement, images of the solder balls **104** in the central image **61**_b_ and the end images **61**_c_ and **61**_d_ can be projection images corresponding to a structure having a common arrangement relation. Accordingly, the part **60**_b_, and the parts **60**_c_ and **60**_d_ including images corresponding to different angle directions of X-rays incident on a structure having a common arrangement relation can be cut out from the teacher X-ray image **60** by acquiring the central image **61**_b_ and the end images **61**_c_ and **61**_d_. For this reason, even in a case in which not the entire teacher X-ray image **60** but images that are cut out corresponding to parts of the teacher X-ray image are used, teacher data can be acquired to properly represent the entire projection image of the teacher X-ray image **60**, and as a result it is possible to prevent accuracy reduction of discrimination result by the learned model **50** generated by machine learning. Therefore, a burden on operators in teacher data production for producing a learned model **50** can be reduced by using the central image **61**_b_ and the end images **61**_c_ and **61**_d_ cut out from the teacher X-ray image **60** while accuracy reduction of discrimination result is prevented.

(68) In addition, additional advantages can be obtained by the aforementioned embodiment added with configurations discussed below.

(69) That is, in this embodiment, as discussed above, the cut-out image acquirer **43** (controller **21**) is configured to acquire a central image **61**_b_ (first image) that is cut out corresponding to a part **60**_b_ (first part) including a central part of the target area **60**_a_ where solder balls **104** (inspection target) are arranged from a teacher X-ray image **60**, and end images **61**_c_ and **61**_d_ (second images) that are cut out corresponding to parts **60**_c_ and **60**_d_ (second parts) each of which includes its corresponding end part of the target area **60**_a_ from the teacher X-ray image. Here, when solder balls **104** are non-destructively inspected by X-ray imaging, X-rays are typically emitted to a center position of an area where the solder balls **104** are arranged as an emission center. In such inspection, a difference between images of the central part and the end parts of a target area **60**_a_ will be large. To address this, in this embodiment, a central image **61**_b_ that is cut out corresponding to a part **60**_b_ including a central part of the target area **60**_a_ from a teacher X-ray image **60**, and end images **61**_c_ and **61**_d_ that are cut out corresponding to parts **60**_c_ and **60**_d_ each of which includes its corresponding end part of the target area **60**_a_ from the teacher X-ray image are acquired. Accordingly, a projected image of the solder balls **104** near the emission center of X-rays can be acquired by acquiring the central image **61**_b_, while projected X-ray images of the solder balls **104** at the most inclined emission direction in the teacher X-ray image **60** can be acquired by acquiring the end images **61**_c_ and **61**_d_. For this reason, teacher data that more properly represents the entire projection image of the teacher X-ray image **60** can be acquired by using the central image **61**_b_, and the end images **61**_c_ and **61**_d_. As a result, it is possible to prevent accuracy reduction of discrimination result by the learned model **50** generated by machine learning.

(70) In this embodiment, as discussed above, the X-ray emitter **11** is configured to emit X-rays to a plurality of solder balls **104** (solder material piece, inspection target) arranged in a grid

arrangement as the regular arrangement; and the discrimination information acquirer **44** (controller **21**) is configured to acquire discrimination images **62***b* to **62***d* which discriminate areas of the solder balls **104** in the central image **61***b* (first image) and the end images **61***c* and **61***d* (second images) as discrimination information. According to this configuration, in a case in which a learned model **50** is produced by using machine learning to analyze solder balls **104** arranged in a grid arrangement as the regular arrangement on a substrate **102**, a burden on operators in the teacher data production for producing the learned model **50** can be reduced.
(71) In this embodiment, as discussed above, a user input acceptor **24** configured to accept an user input instruction is provided; the user input acceptor **24** accepts an area-specifying instruction that specifies the target area **60***a* including the solder balls **104** (inspection target) in the teacher X-ray image **60**; and the cut-out image acquirer **43** (controller **21**) is configured to automatically specify a range of the part **60***b* (first part) and ranges of the parts **60***c* and **60***d* (second parts) from the teacher X-ray image **60** based on the target area **60***a* in the teacher X-ray image **60** specified by the area-specifying instruction accepted by the user input acceptor **24**. According to this configuration, in accordance with the area-specifying instruction that specifies a target area **60***a* so as to include the solder ball **104** arranged in a regular arrangement in teacher X-ray image **60**, a range of the part **60***b* and ranges of the parts **60***c* and **60***d* can be automatically specified so as to properly represent the regular arrangement of the solder balls **104** in the teacher data. For this reason, a burden of specifying a range of the part **60***b* and ranges of the parts **60***c* and **60***d* in consideration of such a regular arrangement of solder balls **104** can be reduced. Therefore, a burden on operators in teacher data production for producing a learned model **50** can be reduced.
(72) In this embodiment, as discussed above, an X-ray imaging system **100** includes a display **23** configured to display the teacher X-ray image **60**, and a user input acceptor **24** configured to accept an user input instruction, wherein the display **23** visually displays an indication indicating a range of the part **60***s* (first part) to be cut out from the teacher X-ray image **60**, and indications indicating ranges of the parts **60***c* and **60***d* (second parts) to be cut out from the teacher X-ray image; and the cut-out image acquirer **43** (controller **21**) specifies the ranges of the parts **60***b*, **60***c* and **60***d* to be cut out from the teacher X-ray image **60** based on the user input instruction accepted by the user input acceptor **24**. According to this configuration, operators (workers) can specify a range of the part **60***b*, and ranges of the parts **60***c* and **60***d* while visually seeing an indication indicating a range of the part **60***b*, and indications indicating ranges of the parts **60***c* and **60***d* indicated on the display **23**. For this reason, operators can see the display **23** and easily specify a range of the part **60***b* and ranges of the parts **60***c* and **60***d* in consideration of a regular arrangement of solder balls **104** (inspection targets). As a result, because teacher data can be acquired based on the central image **61***b* and the end images **61***c* and **61***d*, which are cut out corresponding to suitable parts from the teacher X-ray image **60** in accordance with the regular arrangement of the solder ball **104**, it is possible to more strongly prevent accuracy reduction of discrimination result by the learned model **50** generated by machine learning also in a case in which the teacher data based on the images that are cut out corresponding to parts of the teacher X-ray image is used.
(73) In this embodiment, as discussed above, the cut-out image acquirer **43** (controller **21**) is configured to specify the ranges of the parts **60***b*, **60***c* and **60***d* (first and second parts) which have a size not smaller than a predetermined threshold based on the user input instruction accepted by the user input acceptor **24**. According to this configuration, it is possible to prevent the cut-out ranges of the parts **60***b*, **60***c* and **60***d* from becoming too small. As a result, when machine learning is performed by using teacher data acquired based on the central image **61***b* and the end images **61***c* and **61***d*, it is possible to prevent accuracy reduction of discrimination result by the generated learned model **50**. As a result, in a case in which the ranges of the parts **60***b*, **60***c* and **60***d* are specified in accordance with an input instruction, it is possible to effectively prevent accuracy reduction of discrimination result by the learned model **50** generated by machine learning.
(74) In this embodiment, as discussed above, the controller **21** (model producer) further includes a

teacher data producer **45** configured to generate the input teacher data sets **30***t* based on the central image **61***b* (first image) and the end images **61***c* and **61***d* (second images) acquired by the cut-out image acquirer **43**; and the teacher data producer **45** is configured to adjust the input teacher data sets **30***t* to a common size by using at least one of an alignment in which a plurality of central images **61***b*, which are produced by reproducing the central image, are placed in alignment, and an alignment in which a plurality of end images **61***c* and **61***d*, which are produced by reproducing the end images, are placed in alignment. According to this configuration, in a case in which the input teacher data sets **30***t* are produced based on the central image **61***b* and the end images **61***c* and **61***d*, which are cut out corresponding to different parts, the input teacher data sets **30***t* can be adjusted to a common size, and as a result, it is possible to prevent accuracy reduction of discrimination result by the generated learned model **50**.

(75) In this embodiment, as discussed above, the teacher data producer **45** (controller **21**) is configured to adjust the input teacher data sets **30***t* to a common size by using at least one of an inverse alignment in which the central images **61***b* (first images) are inversely placed in alignment and an inverse alignment in which the end images **61***c* and **61***d* (second images) are inversely placed in alignment. According to this configuration, in a case in which at least one of the central images **61***b* and the end images **61***c* or **61***d* are inversely placed in alignment, smooth boundaries can be obtained between the images placed in alignment by using at least one of an inverse alignment in which the central images **61***b* are inversely placed in alignment and an inverse alignment in which the end images **61***c* and **61***d* are inversely placed in alignment. Accordingly, because sharpness reduction of the images that are placed in alignment can be prevented, it is possible to more strongly prevent accuracy reduction of discrimination result by the generated learned model **50** when input teacher data sets **30***t* are adjusted to a common size.

(76) In this embodiment, as discussed above, the cut-out image acquirer **43** (controller **21**) is configured to acquire a background image **61***e* corresponding to a background part **60***e* cut out from the teacher X-ray image **60** so as to exclude the solder balls **104** (inspection targets); and the learning performer **46** (controller **21**) is configured to perform machine learning for producing a learned model **50** by using the input teacher data sets **30***t* based on the central image **61***b* (first image) and the end images **61***c* and **61***d* (second images), and the background image **61***e*. According to this configuration, machine learning can be performed by using the background image **61***e* corresponding to a cut-out background part **60***e* in addition to the parts **60***b*, part **60***c* and **60***d* of the target area **60***a* including solder balls **104**. As a result, as compared with a case in which machine learning is performed by using teacher data acquired based on the central image **61***b* and the end images **61***c* and **61***d*, accuracy reduction of discrimination result by the generated learned model **50** can be improved by machine learning using the background image **61***e*.

(77) In this embodiment, as discussed above, a user input acceptor **24** configured to accept an user input instruction is provided; the user input acceptor **24** can accept a range-specifying instruction specifying ranges of the parts **60***b*, **60***c* and **60***d* (first and second parts) in one teacher X-ray image **60** among a plurality of the teacher X-ray images **60**; and the cut-out image acquirer **43** (controller **21**) is configured to acquire a plurality of central images **61***b* (first images) corresponding to the common range of the part **60***b*, which is specified in accordance with the range-specifying instruction specified in the one teacher X-ray image **60**, cut out from the plurality of teacher X-ray images **60**, and a plurality of end images **61***c* and **61***d* (second images) corresponding to the common range of the parts **60***c* and **60***d* (second parts), which are specified in accordance with the range-specifying instruction specified in the one teacher X-ray image **60**, cut out from the plurality of teacher X-ray images. According to this configuration, because the common range of the part **60***b*, and the common range of the parts **60***c* and **60***d* can be cut out from a plurality of teacher X-ray images **60**, a plurality of central images **61***b*, and a plurality of end images **61***c* and a plurality of end images **61***d* can be collectively cut out when machine learning is performed by using the plurality of teacher X-ray images **60** including solder balls **104** (inspection targets) having a

common arrangement. Therefore, a burden on operators in teacher data production of teacher data can be reduced in a case in which the teacher data is produced by using a plurality of teacher X-ray images **60**.

(78) Advantages of Learned Model Production Method of the Embodiment

(79) In the learned model production method according to this embodiment, the following advantages are obtained.

(80) In the learned model production method according to this embodiment, as discussed above, a central image **61***b* (first image) that is cut out corresponding to a part **60***b* (first part) from a teacher X-ray image **60** including solder balls **104** (inspection targets) having a regular arrangement, and end images **61***c* and **61***d* (second images) that are cut out corresponding to parts **60***c* and **60***d* (second parts) different from the part **60***b* from the teacher X-ray image can be acquired. Discrimination images **62***b* to **62***d* (discrimination information) to discriminate areas of the solder balls **104** in the central image **61***b*, the end images **61***c* and **61***d* are acquired. Accordingly, the acquired discrimination images **62***b* to **62***d* to discriminate the central image **61***b* of the teacher X-ray image **60** with the part **60***b* being cut out from the teacher X-ray image, and the end images **61***c* and **61***d* of the teacher X-ray image with the parts **60***c* and **60***d* being cut out from the teacher X-ray image can reduce a burden on operators of acquiring the discrimination images **62***b* to **62***d* as compared with a case in which operators acquire the discrimination images **62***b* to **62***d* corresponding to the entire teacher X-ray image **60**. As a result, because a burden on operators of acquiring output teacher data **31***t* to perform machine learning can be reduced, it is possible to provide a learned model production method capable of reducing such a burden on operators in teacher data production for producing a learned model **50** to detect areas of the solder balls **104**. Also, in a case in which X-rays are emitted by a point source of light in X-ray imaging, in a generated X-ray image **30**, a central image in an emission center of X-rays and peripheral images in peripheral parts away from the emission center are images corresponding to different incident angle directions of X-rays different from each other. To address this, in this embodiment, the central image **61***b*, which is cut out corresponding to the part **60***b* from the teacher X-ray image **60** including the solder balls **104** having a regular arrangement, and the end images **61***c* and **61***d*, which are cut out corresponding to the parts **60***c* and **60***d* different from the part **60***b* from the teacher X-ray image, are acquired. Because the solder balls **104** in the teacher X-ray image **60** are arranged in a regular arrangement, images of the solder balls **104** in the central image **61***b* and the end images **61***c* and **61***d* can be projection images corresponding to a structure having a common arrangement relation. Accordingly, the part **60***b*, and the parts **60***c* and **60***d* including images corresponding to different angle directions of X-rays incident on a structure having a common arrangement relation can be cut out from the teacher X-ray image **60** by acquiring the central image **61***b* and the end images **61***c* and **61***d*. For this reason, even in a case in which not the entire teacher X-ray image **60** but images that are cut out corresponding to parts of the teacher X-ray image are used, teacher data can be acquired to properly represent the entire projection image of the teacher X-ray image **60**, and as a result it is possible to prevent accuracy reduction of discrimination result by the learned model **50** generated by machine learning. Therefore, it is possible to provide a learned model production method capable of reducing a burden on operators in teacher data production for producing a learned model **50** by using the central image **61***b* and the end images **61***c* and **61***d* cut out from the teacher X-ray image **60** while preventing accuracy reduction of discrimination result.

(81) Modified Embodiment

(82) Note that the embodiment disclosed this time must be considered as illustrative in all points and not restrictive. The scope of the present invention is not shown by the above description of the embodiments but by the scope of claims for patent, and all modifications (modified examples) within the meaning and scope equivalent to the scope of claims for patent are further included.

(83) For example, while the example in which input teacher data sets **30***t* are produced based on a

central image **61***b* (first image) that is cut out corresponding to a part **60***b* (first part) including a central part of the target area **60***a*, and end images **61***c* and **61***d* (second images) that are cut out corresponding to parts **60***c* and **60***d* (second parts) each of which includes its corresponding end part of the target area **60***a* has been shown in the aforementioned embodiment, the present invention is not limited to this. In the present invention, input teacher data may be produced by acquiring a first image corresponding to a part other than a central part of a target area and a second image corresponding to a other than an end part of the target area.

(84) Also, while the example in which a range of the part **60***b* (first part) and ranges of the parts **60***c* and part **60***d* (second parts) are automatically specified in accordance with an area-specifying instruction that specifies a target area **60***a* has been shown in the aforementioned embodiment, the present invention is not limited to this. In the present invention, ranges of the first and second parts may be separately and directly specified in accordance with area-specifying instructions that specify their corresponding one of the first and second parts.

(85) Also, while the example in which a range of the part **60***b* (first part) or ranges of the parts **60***c* and part **60***d* (second parts) are specified (changed) in accordance with an input instruction has been shown in the aforementioned embodiment, the present invention is not limited to this. In the present invention, no change of one of or both ranges of the first and second parts may be accepted. In other words, when the target area **60***a* is specified, ranges of the first and second parts may be automatically specified, and the first and second images may be then cut out.

(86) Also, while the example in which reproduced images are inversely placed in alignment when input teacher data sets **30***t* are adjusted to a common size has been shown in the aforementioned embodiment, the present invention is not limited to this. In the present invention, images may be placed in alignment without such inverse orientation change when input teacher data is produced.

(87) Also, while the example in which a background image **61***e* corresponding to a cut-out background part **60***e* is acquired to produce a learned model **50** has been shown in the aforementioned embodiment, the present invention is not limited to this. In the present invention, input teacher data may be produced without using such as background image.

(88) Also, while the example in which common ranges of the central image **61***b* (first image) and the end images **61***c* and **61***d* (second images) are acquired from a plurality of teacher X-ray images **60** in accordance with ranges that are specified in one teacher X-ray image **60** has been shown in the aforementioned embodiment, the present invention is not limited to this. In the present invention, in a plurality of teacher X-ray images, different ranges of their first image and different ranges of their second image may be acquired.

(89) Also, while the example in which a learned model **50** is produced to extract areas of solder balls **104** (inspection targets, solder material pieces) in the central image **61***b* (first image) and the end images **61***c* and **61***d* (second images) has been shown in the aforementioned embodiment, the present invention is not limited to this. In the present invention, a learned model may be produced to detect an area of a defect part included in solder ball (inspection target, solder material piece). For example, the discrimination information acquirer may be configured to acquire as the discrimination information a discrimination image that detects an area of avoid (hole) as a defect part included in the solder ball. Also, a learned model may be produced to extract not areas of solder balls in BGA (Ball Grid Array) but areas of a plurality of solder material pieces in connection parts between a plurality of terminals in LGA (Land Grid Array) in which the terminals are arranged in a grid arrangement or an area of a defect part included in the plurality of solder material pieces. Also, a learned model may be produced to not areas of solder material pieces but area of terminals or an area of a defect part included in the terminals.

(90) Also, while the example in which the cut-out image acquirer **43** is configured to acquire two parts **60***c* and **60***d* (second parts) having the same size has been shown in the aforementioned embodiment, the present invention is not limited to this. In the present invention, the cut-out image acquirer may be configured to acquire one second part. In a case in which two second parts are

acquired, the cut-out image acquirer may be configured to acquire two second parts having different size from each other.

(91) Also, while the image generator **13** configured to generate an X-ray image **30** (teacher X-ray image **60**) is provided separately from the controller **21** (model producer) configured to produce a learned model **50** has been shown in the aforementioned embodiment, the present invention is not limited to this. In the present invention, a common control device may be configured to serve to generate the X-ray image and to produce the learned mode. Also, a control device configured to analyze X-ray images by using the learned model may be provided separately from the model producer configured to produce a learned model.

(92) Modes

(93) The aforementioned exemplary embodiment will be understood as concrete examples of the following modes by those skilled in the art.

(94) (Mode Item 1)

(95) An X-ray imaging system includes an X-ray emitter configured to emit X-rays to an inspection target having a regular arrangement; an X-ray detector configured to detect the X-rays emitted from the X-ray emitter; an image generator configured to generate an X-ray image based on the X-rays that are detected by the X-ray detector; and a model producer configured to produce a learned model for analysis of the X-ray image generated by the image generator, wherein the model producer includes a cut-out image acquirer configured to acquire a first image that is cut out corresponding to a first part from a teacher X-ray image including the inspection target having a regular arrangement, and a second image that is cut out corresponding to a second part different from the first part from the teacher X-ray image; a discrimination information acquirer configured to acquire discrimination information to discriminate at least one of an area of the inspection target in the first and second images, and an area of a defect part included in the inspection target in the first and second images; and a learning performer configured to perform machine learning for producing the learned model by using input teacher data sets based on the first and second images, and output teacher data sets based on the discrimination information.

(96) (Mode Item 2)

(97) The X-ray imaging system according to mode item 1, wherein the cut-out image acquirer is configured to acquire the first image which is cut out corresponding to the first part including a center part of a target area including the inspection target from the teacher X-ray image, and the second image which is cut out corresponding to the second part including an end part of the target area from the teacher X-ray.

(98) (Mode Item 3)

(99) The X-ray imaging system according to mode item 1 or 2, wherein the X-ray emitter is configured to emit X-rays to the inspection target which includes a plurality of solder material pieces arranged on a substrate in a grid arrangement as the regular arrangement; and the discrimination information acquirer is configured to acquire a discrimination image in which at least one of an area of the plurality of solder material pieces in the first and second images, and an area of a defect part included in the plurality of solder material pieces in the first and second images is discriminated as the discrimination information.

(100) (Mode Item 4)

(101) The X-ray imaging system according to any of mode items 1 to 3, wherein a user input acceptor configured to accept an user input instruction is further provided; the user input acceptor accepts an area-specifying instruction that specifies a target area including the inspection target in the teacher X-ray image; and the cut-out image acquirer automatically specifies a range of the first part and a range of the second part from the teacher X-ray image based on the target area in the teacher X-ray image specified by the area-specifying instruction accepted by the user input acceptor.

(102) (Mode Item 5)

(103) The X-ray imaging system according to any of mode items 1 to 4, wherein a display configured to display the teacher X-ray image, and a user input acceptor configured to accept an user input instruction are further provided; and the display visually displays an indication indicating a range of the first part to be cut out from the teacher X-ray image and an indication indicating a range of the second part to be cut out from the teacher X-ray image; and the cut-out image acquirer specifies the ranges of the first and second parts to be cut out from the teacher X-ray image based on the user input instruction accepted by the user input,
(104) (Mode Item 6)
(105) The X-ray imaging system according to mode item 5, wherein the cut-out image acquirer specifies the ranges of the first and second parts which have a size not smaller than a predetermined threshold based on the user input instruction accepted by the user input acceptor.
(106) (Mode Item 7)
(107) The X-ray imaging system according to any of mode items 1 to 6, wherein the model producer further includes a teacher data producer configured to generate the input teacher data sets based on the first and second images acquired by the cut-out image acquirer; and the teacher data producer is configured to adjust the input teacher data sets to a common size by using at least one of an alignment in which a plurality of first images, which are produced by reproducing the first image, are placed in alignment, and an alignment in which a plurality of second images, which are produced by reproducing the second image, are placed in alignment.
(108) (Mode Item 8)
(109) The X-ray imaging system according to mode item 7, wherein the teacher data producer is configured to adjust the input teacher data sets to the common size by using at least one of an inverse alignment in which the first images are inversely placed in alignment, and an inverse alignment in which the second images are inversely placed in alignment
(110) (Mode Item 9)
(111) The X-ray imaging system according to any of mode items 1 to 8, wherein the cut-out image acquirer acquires a background image corresponding to a background part cut out from the teacher X-ray image so as to exclude the inspection target; and the learning performer is configured to perform machine learning for producing a learned model by using the input teacher data sets based on the first and second images, and the background image.
(112) (Mode Item 10)
(113) The X-ray imaging system according to any of mode items 1 to 9, wherein a user input acceptor configured to accept an user input instruction is further provided; the user input acceptor accepts a range-specifying instruction specifying ranges of the first and second parts in one teacher X-ray image among a plurality of the teacher X-ray images; and the cut-out image acquirer acquires a plurality of first images corresponding to a common range of the first part, which is specified in accordance with the range-specifying instruction specified in the one teacher X-ray image, cut out from the plurality of teacher X-ray images, and a plurality of second images corresponding to a common range of the second part, which is specified in accordance with the range-specifying instruction specified in the one teacher X-ray image, cut out from the plurality of teacher X-ray images.
(114) (Mode Item 11)
(115) A learned model production method includes a step of acquiring a first image that is cut out corresponding to a first part from a teacher X-ray image corresponding to an X-ray image generated by irradiating an inspection target having a regular arrangement with X-rays, and a second image that is cut out corresponding to a second part different from the first part from the teacher X-ray image; a step of acquiring discrimination information to discriminate at least one of an area of the inspection target in the first and second images, and an area of a defect part included in the inspection target in the first and second images; and a step of performing machine learning for producing a learned model for analysis of the X-ray image by using input teacher data sets

based on the first and second images, and output teacher data sets based on the discrimination information.

Claims

1. An X-ray imaging system comprising: an X-ray emitter configured to emit X-rays to an inspection target having a regular arrangement; an X-ray detector configured to detect the X-rays emitted from the X-ray emitter; an image generator configured to generate an X-ray image based on the X-rays that are detected by the X-ray detector; and a model producer configured to produce a learned model for analysis of the X-ray image generated by the image generator, wherein the model producer includes a cut-out image acquirer configured to acquire a first image that is cut out corresponding to a first part from a teacher X-ray image including the inspection target having a regular arrangement, and a second image that is cut out corresponding to a second part different from the first part from the teacher X-ray image; a discrimination information acquirer configured to acquire discrimination information to discriminate at least one of an area of the inspection target in the first and second images, and an area of a defect part included in the inspection target in the first and second images; and a learning performer configured to perform machine learning for producing the learned model by using input teacher data sets based on the first and second images, and output teacher data sets based on the discrimination information.
2. The X-ray imaging system according to claim 1, wherein the cut-out image acquirer is configured to acquire the first image which is cut out corresponding to the first part including a center part of a target area including the inspection target from the teacher X-ray image, and the second image which is cut out corresponding to the second part including an end part of the target area from the teacher X-ray image.
3. The X-ray imaging system according to claim 1, wherein the X-ray emitter is configured to emit X-rays to the inspection target which includes a plurality of solder material pieces arranged on a substrate in a grid arrangement as the regular arrangement; and the discrimination information acquirer is configured to acquire a discrimination image in which at least one of an area of the plurality of solder material pieces in the first and second images, and an area of a defect part included in the plurality of solder material pieces in the first and second images is discriminated as the discrimination information.
4. The X-ray imaging system according to claim 1 further comprising a user input acceptor configured to accept an user input instruction, wherein the user input acceptor accepts an area-specifying instruction that specifies a target area including the inspection target in the teacher X-ray image; and the cut-out image acquirer automatically specifies a range of the first part and a range of the second part from the teacher X-ray image based on the target area in the teacher X-ray image specified by the area-specifying instruction accepted by the user input acceptor.
5. The X-ray imaging system according to claim 1 further comprising a display configured to display the teacher X-ray image, and a user input acceptor configured to accept an user input instruction, wherein the display visually displays an indication indicating a range of the first part to be cut out from the teacher X-ray image and an indication indicating a range of the second part to be cut out from the teacher X-ray image; and the cut-out image acquirer specifies the ranges of the first and second parts to be cut out from the teacher X-ray image based on the user input instruction accepted by the user input acceptor.
6. The X-ray imaging system according to claim 5, wherein the cut-out image acquirer specifies the ranges of the first and second parts which have a size not smaller than a predetermined threshold based on the user input instruction accepted by the user input acceptor.
7. The X-ray imaging system according to claim 1, wherein the model producer further includes a teacher data producer configured to generate the input teacher data sets based on the first and second images acquired by the cut-out image acquirer; and the teacher data producer is configured

to adjust the input teacher data sets to a common size by using at least one of an alignment in which a plurality of first images, which are produced by reproducing the first image, are placed in alignment, and an alignment in which a plurality of second images, which are produced by reproducing the second image, are placed in alignment.

8. The X-ray imaging system according to claim 7, wherein the teacher data producer is configured to adjust the input teacher data sets to the common size by using at least one of an inverse alignment in which the first images are inversely placed in alignment, and an inverse alignment in which the second images are inversely placed in alignment.

9. The X-ray imaging system according to claim 1, wherein the cut-out image acquirer acquires a background image corresponding to a background part cut out from the teacher X-ray image so as to exclude the inspection target; and the learning performer is configured to perform machine learning for producing a learned model by using the input teacher data sets based on the first and second images, and the background image.

10. The X-ray imaging system according to claim 1 further comprising a user input acceptor configured to accept an user input instruction, wherein the user input acceptor accepts a range-specifying instruction specifying ranges of the first and second parts in one teacher X-ray image among a plurality of the teacher X-ray images; and the cut-out image acquirer acquires a plurality of first images corresponding to a common range of the first part, which is specified in accordance with the range-specifying instruction specified in the one teacher X-ray image, cut out from the plurality of teacher X-ray images, and a plurality of second images corresponding to a common range of the second part, which is specified in accordance with the range-specifying instruction specified in the one teacher X-ray image, cut out from the plurality of teacher X-ray images.

11. A learned model production method comprising: a step of acquiring a first image that is cut out corresponding to a first part from a teacher X-ray image corresponding to an X-ray image generated by irradiating an inspection target having a regular arrangement with X-rays, and a second image that is cut out corresponding to a second part different from the first part from the teacher X-ray image; a step of acquiring discrimination information to discriminate at least one of an area of the inspection target in the first and second images, and an area of a defect part included in the inspection target in the first and second images; and a step of performing machine learning for producing a learned model for analysis of the X-ray image by using input teacher data sets based on the first and second images, and output teacher data sets based on the discrimination information.