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## ENHANCED PRINT DEFECT DETECTION


### Abstract

Systems and methods are provided for. One embodiment is a system that includes an interface configured to receive an image of media printed on with print data, and memory configured to store defect reference data of nozzles belonging to printheads of a printer. The system also includes a print defect controller configured to detect a nozzle defect in the image based on a comparison of the image with the print data, and to determine a type of the nozzle defect based on a comparison of the nozzle defect with the defect reference data.



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## Background/Summary

RELATED APPLICATIONS [0001] This non-provisional patent application is a continuation of U.S. patent application Ser. No. 18/218,052 filed on Jul. 4, 2023, which is incorporated herein by reference.

TECHNICAL FIELD
[0002] The invention relates to the field of printing, and in particular, to detecting print defects.
BACKGROUND
[0003] An inkjet production printer is a high-speed printer used for volume printing (e.g., one hundred pages per minute or more), and may include continuous-forms printers that print on a web of print media stored on a large roll. While a continuous-forms inkjet printer operates, the web is quickly passed underneath the nozzles of printheads of the printer, which discharge ink onto the web at intervals to form pixels.
[0004] Although most of the ink dispensed by the printheads is transferred to the web, some amount of ink remains on the nozzles of the printheads. Over time, congealed ink, contaminants, or nozzle structural failures may form which clogs or partially clogs nozzles, resulting in defective ink jets that degrades print quality. Determining the particular type and location of a print defect informs follow-up decisions (e.g., cleaning operations) to compensate for the print defect and improve print quality.
[0005] Print defect identification is typically performed manually by a trained print operator at the beginning of a day or print cycle. However, even if the operator has a lot of experience and training to distinguish among the various types of print defects, human print defect analysis is time consuming and subject to inaccuracies.
SUMMARY
[0006] Embodiments herein describe enhanced print defect detection. A defect detection system of a printer distinguishes between different types of print defects automatically with high precision and speed. Using reference data of previously identified defect types, the defect detection system is able to determine the location and type of defect for individual nozzles of the printer. Types of nozzle defects present in a printhead are determined quickly and accurately, and may be used to inform maintenance decisions for improved efficiency of maintenance procedures performed for the printer.
[0007] One embodiment is a system that includes an interface configured to receive an image of media printed on with print data, and memory configured to store defect reference data of nozzles belonging to printheads of a printer. The system also includes a print defect controller configured to detect a nozzle defect in the image based on a comparison of the image with the print data, and to determine a type of the nozzle defect based on a comparison of the nozzle defect with the defect reference data.

[0008] Another embodiment is a method that includes storing, in memory, defect reference data of nozzles belonging to printheads of a printer. The method also includes receiving an image of media printed on with print data, and detecting a nozzle defect in the image based on a comparison of the image with the print data. The method further includes determining a type of the nozzle defect based on a comparison of the nozzle defect with the defect reference data.
[0009] Other illustrative embodiments (e.g., methods and computer-readable media relating to the foregoing embodiments) may be described below.

## Description

DESCRIPTION OF THE DRAWINGS
[0010] Some embodiments of the present invention are now described, by way of example only, and with reference to the accompanying drawings. The same reference number represents the same element or the same type of element on all drawings.
[0011] FIG. **1** is a diagram of a printing system in an illustrative embodiment.
[0012] FIG. **2**A shows jet-out defects on the test chart.
[0013] FIG. **2**B shows a deviated jet defect on the test chart.
[0014] FIG. **2**C shows delaminated head defects on the test chart.
[0015] FIG. **2**D shows an unknown defect on the test chart.
[0016] FIG. **3** is a block diagram of a printer in an illustrative embodiment.
[0017] FIG. **4** is a flowchart illustrating a method of determining a type of print defect in an illustrative embodiment.
[0018] FIG. **5** is a flowchart illustrating a method of determining a type of print defect in another illustrative embodiment.
[0019] FIG. **6** is a block diagram of the defect detection system implementing a machine learning function in an illustrative embodiment.
[0020] FIG. **7** illustrates a processing system operable to execute a computer readable medium embodying programmed instructions to perform desired functions in an illustrative embodiment.
DETAILED DESCRIPTION
[0021] The figures and the following description illustrate specific illustrative embodiments. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the embodiments and are included within the scope of the embodiments. Furthermore, any examples described herein are intended to aid in understanding the principles of the embodiments, and are to be construed as being without limitation to such specifically recited examples and conditions. As a result, the inventive concept(s) is not limited to the specific embodiments or examples described below, but by the claims and their equivalents.
[0022] FIG. **1** is a diagram of a print system **100** in an illustrative embodiment. The print system **100** includes a printer **120** and a defect detection system **150**. Under normal printing operation, the printer **120** receives a print job, generates rasterized print data for the print job with the print controller **126**, and transmits the rasterized print data for the print job to one or more print engines **127-128**. The print engines **127-128** mark the web **130** of print media (e.g., paper, textile, printable substrate) with ink (e.g., marking material, colorant, etc.) according to the rasterized print data, thus producing printed output.
[0023] Occasionally, to verify that the print engines **127-128** are operating correctly, the print controller **126** instructs the print engines **127-128** to print a test chart **140** based on test chart print data onto web **130** that can be analyzed manually or by the defect detection system **150** for print defects. The defect detection system **150** includes an interface **152**, a defect controller **154**, and one or more imaging device(s) **156**. The imaging device **156** may comprise a camera, scanner,

densitometer, spectrophotometer or other suitable component for acquiring images of printed content. The test chart **140** may be printed on the web **130** separately from the print jobs or with the print jobs (e.g. on sections of the web **130** separate from the sections of the web **130** printed with the print jobs).

[0024] After obtaining an image of the test chart **140** via the imaging device **156**, the defect controller **154** analyzes the image for jet defects. For example, the defect controller **154** may be configured to determine which printheads or nozzles printed the defects based on the location of the defect in the test chart **140**. The defect detection system **150** and printer **120** may communicate via interfaces **122**/**152** (e.g., an Ethernet interface, wireless interface, etc.). For instance, the print controller **126** may transmit a rasterized version of the print data corresponding to test chart **140** to the defect detection system **150** for comparison to an image of the test chart **140** to determine whether there are any discrepancies that indicate printing errors, and the defect detection system **150** may report (e.g., transmit) print defect data to the printer **120** or other systems to inform maintenance procedures.

[0025] As described in greater detail below, the defect controller **154** is enhanced to classify print defects by category or type. FIGS. **2**A-D illustrate different types of print defects. FIG. **2**A shows jet-out defects **201** on the test chart **140**. Jet-out defects **201** may be caused by a complete blocking of a nozzle (e.g., no ink ejected). FIG. **2**B shows a deviated jet defect **202** on the test chart **140**. Deviated jet defects **202** may be caused by a partial blocking of a nozzle (e.g., ink ejected at least partially to an unintended location on web **130**). FIG. **2**C shows delaminated print head defects **203** on the test chart **140**. Delaminated head defects **203** may be caused by film on the printhead array peeling off from wear and tear (e.g., a plurality of adjacent nozzles partially blocked or fully blocked). FIG. **2**D shows an unknown defect **204** on the test chart **140**. Unknown defects **204** may comprise a category of defects other than that which can be classified into the other print defect categories. Those skilled in the art will appreciate that further nozzle defect types or sub-types may also be defined.

[0026] FIG. **3** is a block diagram of a printer **300** in an illustrative embodiment. The printer **300** includes the defect detection system **150** enhanced to determine the type or category of a particular print defect. That is, the defect detection system **150** is configured to categorize print defects as one of a jet-out defect **201**, deviated jet defect **202**, delaminated head defect **203**, or unknown defect **204**. By classifying print defects by type, the defect detection system **150** is able to provide operational health data of the printer **300** and facilitate corrective actions to take for efficiently improving print quality. Those skilled in the art will appreciate that defect detection system **150** may be used for other defect types also.

[0027] The printer **300** generally includes a plurality of color planes **330** (e.g., cyan, magenta, yellow, and black) and print engines **332**. Each print engine **332** may process print data for one or a plurality of color planes **330** and control one or a plurality of printheads **334** based on the print data. Each printhead **334** includes an array of nozzles **336** that eject drops of ink **338** for printing. The nozzles **336** of each printhead **334** may be assigned to one color plane or divided between a plurality of color planes **330**. The printheads **334** may be configured physically in the web direction and/or orthogonal to the web direction. As earlier described, in the course of a normal printing operation, one or more of the nozzles **336** may clog with ink, resulting in print defects. Additionally, each printhead **334** may include hundreds of nozzles **336**. Due to quantity of ink drops **338** jetted by nozzles **336**, the small individual size of the ink drops **338**, and similarities in resemblance of different defect types to the human eye, it is difficult and time consuming even for a trained print operator to analyze printed test charts for defect types.

[0028] The defect detection system **150** is enhanced with the defect controller **154** configured to detect a nozzle defect in an image based on a comparison of the image with print data **356**, and to determine a type of the nozzle defect based on a comparison of the nozzle defect with the defect reference data. In doing so, the defect controller **154** may take into account data stored in data storage **350**, including any combination of current nozzle defect information **351**, defect reference data **352**, and print system settings **353**. Examples of current nozzle defect information **351** include any combination of nozzle defect type, corresponding nozzle **336** location, corresponding printhead **334** identification, corresponding print engine **332**, corresponding printer **300** and/or color plane **330**. Examples of print system settings **353** include a print resolution, selected test pattern type, media type, and/or print engine parameters (e.g., print engine model, print width, paper handling orientation in the print engine, printhead type, ink type, etc.).

[0029] The data storage **350** may also store image data **355** of the test chart **140** captured by the imaging device **156** and/or print data **356** corresponding to the test chart **140**. Additionally, the data storage **350** may store printer configuration information **354** that may comprise information that correlates print locations, nozzles **336**, printheads **334**, print engines **332**, color planes **330**, and/or ink types (e.g. ink sets or specific ink colors). The defect controller **154** may be communicatively coupled with an interface **346** and/or a graphical user interface **348** for receiving user input and/or displaying notifications to the user of the printer **300**.

[0030] While the specific hardware implementation of the defect controller **154** is subject to design choices, one particular embodiment may include one or more processors **342** coupled with a memory **344**. The processor **342** includes any electronic circuits and/or optical circuits that are able to perform functions. For example, a processor may include one or more Central Processing Units (CPU), Graphics Processing Unit (GPU), microprocessors, Digital Signal Processors (DSPs), Application-Specific Integrated Circuits (ASICs), Programmable Logic Devices (PLD), control circuitry, etc. Some examples of processors include Intel Core processors, Advanced Reduced Instruction Set Computing (RISC) Machines (ARM) processors, etc. The memory **344** includes any hardware device that is able to store data. The memory **344** may include one or more volatile or non-volatile Dynamic Random Access Memory (DRAM) devices, FLASH devices, volatile or non-volatile Static RAM devices, hard drives, Solid State Disks (SSDs), etc. Some examples of non-volatile DRAM and SRAM include battery-backed DRAM and battery-backed SRAM. The data storage **350** may similarly be implemented by any combination of memory devices or components.

[0031] The particular arrangement, number, and configuration of components described with respect to FIG. **3** is an example for purposes of discussion and are non-limiting. For example, although the defect detection system **150** is shown as incorporated in the printer **300**, portions or an entirety of the defect detection system **150** and functions performed thereby may be implemented in a separate system that is near to the printer **300** (e.g. Digital Front End (DFE)) or remotely as a standalone system (e.g., cloud implementation) in communication with the printer **300**. Illustrative details of the operation of the defect detection system **150** will be discussed with regard to FIGS. **4-5**.

[0032] FIG. **4** is a flowchart illustrating a method **400** of determining a type of print defect in an illustrative embodiment. The steps of method **400** are described with reference to the printer **300** and defect detection system **150** of FIG. **3**, but those skilled in the art will appreciate that method **400** may be performed in other systems. The steps of the flowcharts described herein are not all inclusive and may include other steps not shown. The steps described herein may also be optionally performed or performed in an alternative order.

[0033] In step **402**, the defect controller **154** may receive (e.g., via interface **346**) and/or store (e.g., in data storage **350** or a memory) print data (e.g., print data **356**), and an image of media printed on with the print data (e.g., image data **355**). Print data **356** corresponds to the source print data that instructed the printing of test chart **140** and may be in any suitable format for processing such as bitmaps, print description language or print job. In some embodiments, print data **356** for a test chart is incorporated and available within defect reference data **352**. In step **404**, the defect controller **154** stores (e.g., in data storage **350** or a memory) defect reference data **352** of nozzles **336** belonging to printheads **334** of a printer **300**. The defect reference data **352** may include rules and/or characteristics (e.g., defect image patterns) for the defect controller **154** to use for interpreting the input image and determining defect types. In some embodiments, defect reference data **352** includes rules for determining optical density variations beyond a threshold (e.g., missing or unintended ink placement) in image data **355** locations using a template based on test chart **140**. The defect reference data **352** may be derived from images that exhibit characteristics of a previously-defined print defect type. For example, the defect reference data **352** may be based on example print defect images that have been previously categorized either manually or by the defect controller **154**. Defect reference data **352** may be available for each category of print defects (e.g., a jet-out defect category, deviated defect category, delaminated head defect category, and an unknown category).

[0034] In step **406**, the defect controller **154** detects a nozzle defect in the image based on a comparison of the image with the print data **356**. In doing so, the defect controller **154** may analyze image data **355** of the test chart **140** for discrepancies with print data **356** and stores current nozzle defect information **351** in data storage **350**. Additionally, the defect controller **154** may correlate defect locations within the test chart **140** or image data **355** with individual nozzles **336**, printheads **334**, print engines **332**, and/or printer **300** that printed a defect based on information of the printer configuration **354** and/or print data **356** stored in data storage **350**.

[0035] In step **408**, the defect controller **154** determines a type of the nozzle defect based on a comparison of the nozzle defect image characteristics with the defect reference data **352**. For instance, the defect controller **154** may identify a matching or similar pattern in the defect reference data **352** or a common characteristic among defects within the same category, and determine the category to which the nozzle defect belongs based on a match of characteristics in the nozzle defect with that in the pattern or commonality defined in the defect reference data **352**. As earlier described, the defect controller **154** may determine whether the nozzle defect is one of a jet-out (caused due to complete blocking of a nozzle), a deviated jet (caused by a partial blocking of a nozzle), delaminated head (caused by film on the printhead array peeling off from wear and tear), and unknown (other causes). In some embodiments, the defect controller **154** determines a type of the nozzle defect with look up tables, programmed logic, and/or trained machine learning processor(s). The method **400** provides a benefit over prior techniques by assigning a print defect to a particular classification of inkjet nozzle defects without reliance on trained human operators.

[0036] FIG. **5** is a flowchart illustrating a method **500** of determining a type of print defect in another illustrative embodiment. The steps of method **500** are described with reference to the printer **300** and defect detection system **150** of FIG. **3**, but those skilled in the art will appreciate that method **500** may be performed in other systems. The steps of the flowcharts described herein are not all inclusive and may include other steps not shown. The steps described herein may also be optionally performed or performed in an alternative order.

[0037] In step **502**, the imaging device **156** scans or captures a printed test chart to create a grayscale image (e.g., image data **355**). If image data **355** has been stored in data storage **350**, then step **502** may be optionally skipped. In step **504**, the defect controller **154** aligns the grayscale image with the print data **356**. The alignment may include adjustment of comparison inputs to account for the edge registration of print engine(s) **332** (e.g., center, left, or right justified) and/or skew. For example, if the printed test master is not printed on a full width of the medium, the defect controller **154** may align the image to left if a first print engine printed the chart, and align the image to the right if a second print engine printed the test chart. Additionally, the defect controller **154** may adjust image data **355** for stretching/shrinkage in the printed medium, and may apply a position correction that is varied for each printhead to better align the grayscale image to the print data **356** for each specific printhead.

[0038] In step **506**, the defect controller **154** determines defect information of one or more print defects in the grayscale image. And, in step **508**, the defect controller **154** determines the type of nozzle defect with a machine learning function using the defect information as input to the machine learning function. FIG. **6** is a block diagram of the defect detection system **150** implementing a machine learning function in an illustrative embodiment. The defect detection system **150** includes a trained Deep Neural Network (DNN) processor **610** to automatically detect and localize multiple types of jetting defects at an individual nozzle level.

[0039] The DNN processor **610** receives trained input via training input **612** that takes into account a model **614** and defect information **616**. The trained DNN processor **610** is configured to produce inference **620** that analyzes pixels in the greyscale image **622** and assigns a defect type **624** to an individual pixel based on pattern recognition. In some embodiments, the trained DNN processor **610** implements as class of neural networks referred to as Convolutional Neural Networks (CNN). In some embodiments, the DNN processor **610** is trained with training input **612** that includes test chart **140** of method **500**.

[0040] Returning to FIG. **5**, step **508** may comprise further steps **510-512**. In step **510**, the trained DNN processor **610** detects types of print defects based on a comparison of the greyscale image **622** with the print data **356**, and also based on defect information **616** input to the trained DNN processor **610**. The defect information **616** may include the defect reference data **352**, defect location, and/or print system settings **353**. For example, the trained DNN processor **610** may determine the type of print defect based, at least part, on the print engine **332** that printed the defect and the location of the defect relative to the print engine **332**. In some embodiments, the model **614** may be trained specific to a print engine **332**, printhead **334**, media type, etc. to adapt to changing configurations/specifications of the printer **300** to obtain higher detection accuracy.

[0041] In step **512**, the trained DNN processor **610** determines a degree of matching between a nozzle defect detected in the greyscale image **622** and the defect reference data **352** for one of or each category of print defect. The degree of matching may include a percentage between zero and one hundred indicating a prediction or confidence level that the nozzle defect belongs to one of the specific predefined nozzle defects in the defect reference data **352**. In step **514**, the defect controller **154** reports the nozzle defect location and confidence level that the assigned type of defect is correct for the nozzle defect.

[0042] In step **516**, the defect controller **154** determines whether the degree of matching is uncertain for the nozzle defect (e.g., whether the degree of matching is beyond a threshold for each category of defect). If so, the method **500** proceeds to step **518**, and the defect controller **154** generates a message for display indicating to perform a manual review of the nozzle defect. Then, in step **520**, the defect controller **154** updates the defect reference data **352** based on received manual review data of the nozzle defect (e.g., reviewed nozzle defect data received via GUI **348** and/or I/F **346**), and the method **500** returns to step **508**. Accordingly, the trained DNN processor **610** may generate pixel masks for different defect categories trained with hand-labeled datasets. This enables the trained DNN processor **610** to adapt to real world input variation and noise in the original training set to continuously improve defect type prediction accuracy. Moreover, difficult cases with low confidence scores may be automatically collected to grow the training dataset, and other sub-categories of unknown defects may be discovered and incorporated in the future.

[0043] Otherwise, if the degree of matching is certain, the method **500** proceeds to step **522** and the defect controller **154** determines whether there are additional defects in the greyscale image **622**. If so, the method **500** returns to step **508** and repeats. Otherwise, the method **500** ends. Accordingly, the method **500** provides a benefit over prior techniques by rapidly and automatically distinguishing between different types of print defects with high accuracy. Although certain steps of method **500** are described with respect to the defect controller **154** or the trained DNN processor **610**, it will be appreciated that the steps of the method **500** may optionally be performed in alternative systems or types of processor(s).

[0044] Embodiments disclosed herein can take the form of software, hardware, firmware, or various combinations thereof. In one particular embodiment, software is used to direct a processing system of the defect detection system **150** to perform the various operations disclosed herein. FIG. **7** illustrates a processing system **700** operable to execute a computer readable medium embodying programmed instructions to perform desired functions in an illustrative embodiment. Processing system **700** is operable to perform the above operations by executing programmed instructions tangibly embodied on computer readable storage medium **712**. In this regard, embodiments of the invention can take the form of a computer program accessible via computer-readable medium **712** providing program code for use by a computer or any other instruction execution system. For the purposes of this description, computer readable storage medium **712** can be anything that can contain or store the program for use by the computer.

[0045] Computer readable storage medium **712** can be an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor device. Examples of computer readable storage medium **712** include a solid state memory, a magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk, and an optical disk. Current examples of optical disks include compact disk-read only memory (CD-ROM), compact disk-read/write (CD-R/W), and DVD.

[0046] Processing system **700**, being suitable for storing and/or executing the program code, includes at least one processor **702** coupled to program and data memory **704** through a system bus **750**. Program and data memory **704** can include local memory employed during actual execution of the program code, bulk storage, and cache memories that provide temporary storage of at least some program code and/or data in order to reduce the number of times the code and/or data are retrieved from bulk storage during execution.

[0047] Input/output or I/O devices **706** (including but not limited to keyboards, displays, pointing devices, etc.) can be coupled either directly or through intervening I/O controllers. Network adapter interfaces **708** may also be integrated with the system to enable processing system **700** to become coupled to other data processing systems or storage devices through intervening private or public networks. Modems, cable modems, IBM Channel attachments, SCSI, Fibre Channel, and Ethernet cards are just a few of the currently available types of network or host interface adapters. Display device interface **710** may be integrated with the system to interface to one or more display devices, such as printing systems and screens for presentation of data generated by processor **702**.

[0048] Although specific embodiments were described herein, the scope of the invention is not limited to those specific embodiments. The scope of the invention is defined by the following claims and any equivalents thereof.

## Claims

**1**. A defect detection system comprising: a machine learning model trained to classify nozzle defects as one of a plurality of nozzle defect types based on pattern recognition of pixels in input image data and pixels in reference images previously categorized according to the nozzle defect types; and one or more processors configured to receive a print image of printing on a print media by one or more printheads based on print data, and to input the print image and the print data into the machine learning model to assign one of the nozzle defect types to a nozzle defect detected in the print image.

**2**. The defect detection system of claim 1, wherein: the machine learning model is configured to output a confidence level that the nozzle defect detected in the print image belongs to the one of the nozzle defect types.

**3**. The defect detection system of claim 1, wherein: the print image input into the machine learning model comprises a grayscale image.

**4**. The defect detection system of claim 1, wherein: assignment of the one of the nozzle defect types to the nozzle defect via the machine learning model is performed during a printing operation of a print job.

**5**. The defect detection system of claim 1, wherein: the one or more processors are configured to localize the nozzle defect at an individual nozzle level.

**6**. The defect detection system of claim 1, wherein: the one or more processors are configured to correlate a location of the nozzle defect with one or more individual nozzles of the one or more printheads.
**7**. The defect detection system of claim 6, wherein: the one or more processors are configured to correlate the location of the nozzle defect based on printer configuration information of a printer comprising the one or more printheads.
**8**. The defect detection system of claim 1, wherein: the one or more processors are configured to input at least one print system setting into the machine learning model.
**9**. The defect detection system of claim 1, further comprising: an imaging device configured to capture the print image of the printing on the print media by the one or more printheads during a printing operation of a print job.
**10**. The defect detection system of claim 9, wherein: the print image comprises a test chart printed on the print media by the one or more printheads based on test chart print data; and the test chart is printed on a section of the print media separate from a section of the print media printed with the print job.
**11**. The defect detection system of claim 1, wherein the nozzle defect types comprise at least two of: a jet-out defect caused by complete blocking of a nozzle; a deviated jet defect caused by partial blocking of a nozzle; and a delaminated head defect.
**12**. The defect detection system of claim 1, wherein: the machine learning model comprises a neural network.
**13**. A print system comprising: a printer comprising the one or more printheads; and the defect detection system of claim 1.
**14**. A method comprising: implementing a machine learning model trained to classify nozzle defects as one of a plurality of nozzle defect types based on pattern recognition of pixels in input image data and pixels in reference images previously categorized according to the nozzle defect types; receiving a print image of printing on a print media by one or more printheads based on print data; and inputting the print image and the print data into the machine learning model to assign one of the nozzle defect types to a nozzle defect detected in the print image.
**15**. The method of claim 14, wherein: the machine learning model is configured to output a confidence level that the nozzle defect detected in the print image belongs to the one of the nozzle defect types.
**16**. The method of claim 14, wherein: the inputting comprises inputting the print image into the machine learning model as a grayscale image.
**17**. The method of claim 14, wherein: assignment of the one of the nozzle defect types to the nozzle defect via the machine learning model is performed during a printing operation of a print job.
**18**. The method of claim 14, further comprising: localizing the nozzle defect at an individual nozzle level.
**19**. The method of claim 14, further comprising: correlating a location of the nozzle defect with one or more individual nozzles of the one or more printheads.
**20**. A non-transitory computer readable medium including programmed instructions which, when executed by one or more processors, are operable for performing a method comprising: implementing a machine learning model trained to classify nozzle defects as one of a plurality of nozzle defect types based on pattern recognition of pixels in input image data and pixels in reference images previously categorized according to the nozzle defect types; receiving a print image of printing on a print media by one or more printheads based on print data; and inputting the print image and the print data into the machine learning model to assign one of the nozzle defect types to a nozzle defect detected in the print image.