(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
20 February 2020 (20.02.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/035766 A1

(51) International Patent Classification:
B41J 2/21 (2006.01) *G06K 15/02* (2006.01)

(21) International Application Number:
PCT/IB2019/056746

(22) International Filing Date:
08 August 2019 (08.08.2019)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/717,957 13 August 2018 (13.08.2018) US

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

(54) Title: CORRECTING DISTORTIONS IN DIGITAL PRINTING BY IMPLANTING DUMMY PIXELS IN A DIGITAL IMAGE

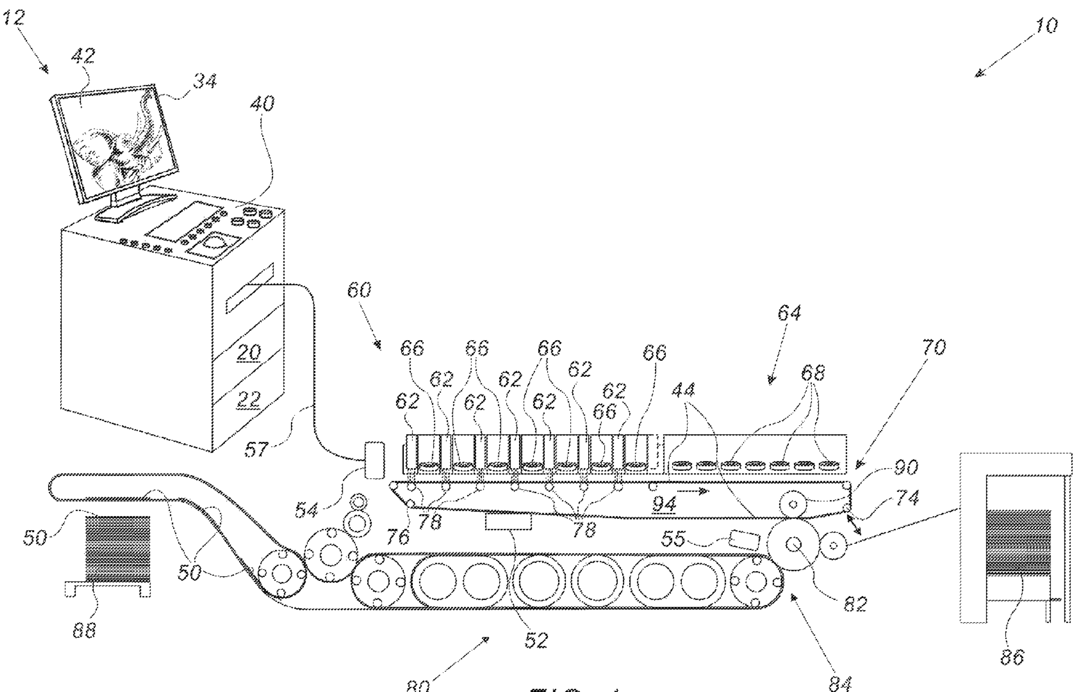


FIG. 1

(57) Abstract: A method for correcting distortion in image printing, the method includes receiving a digital image (200, 306, 376, 500, 600, 700, 810) acquired from a printed image. Based on the digital image (200, 306, 376, 500, 600, 700, 810), a geometric distortion in the printed image is estimated. One or more pixel locations (228, 504, 506, 514, 610, 620, 630, 640, 712, 716, 722, 724) are calculated, such that, when one or more dummy pixels (232, 234) are implanted therein, compensate for the estimated geometric distortion. The geometric distortion is corrected in a subsequent digital image to be printed, by implanting the one or more dummy pixels (232, 234) at the one or more calculated pixel locations (228, 504, 506, 514, 610, 620, 630, 640, 712, 716, 722, 724) in the subsequent digital image. The subsequent digital image having the corrected geometric distortion is printed.

WO 2020/035766 A1

[Continued on next page]

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

Published:

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

CORRECTING DISTORTIONS IN DIGITAL PRINTING BY IMPLANTING DUMMY PIXELS IN A DIGITAL IMAGE

FIELD OF THE INVENTION

The present invention relates generally to digital printing, and particularly to methods and systems for compensating for distortions in digitally printed images.

BACKGROUND OF THE INVENTION

Various methods and systems for correcting distortions in digitally printed images are known in the art.

For example, U.S. Patent 6,966,712 describes a method and system including printing a test pattern on a print medium and generating a digital image of the printed test pattern using an imaging device. The method and system include analyzing an interference pattern to measure for distortion of the print medium and calibrating the printing device based upon the measured distortion.

U.S. Patent Application Publication 2017/0104887 describes an image processing apparatus that includes an image processing unit configured to execute, in forming an image on both surfaces of a sheet, image processing. The image processing includes skew correction to deform the image in advance to offset distortion to be caused in the image to be formed on the sheet.

U.S. Patent 8,891,128 describes a defective recording element detecting apparatus. The apparatus includes a read image data acquiring device, a reference area setting device, a comparison area setting device, a correlation operation device, a distortion correction value determining device, an image distortion correcting device, and a defective recording element determining device.

SUMMARY OF THE INVENTION

An embodiment of the present invention that is described herein provides a method for correcting distortion in image printing, the method including receiving a digital image acquired from a printed image. Based on the digital image, a geometric distortion is estimated in the printed image. One or more pixel locations are calculated, such that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion. The geometric distortion is corrected in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image. The subsequent digital image, having the corrected geometric distortion, is printed.

In some embodiments, implanting the one or more dummy pixels at a calculated pixel location includes shifting one or more existing pixels at a given pixel location by an amount of the implanted one or more dummy pixels. In other embodiments, at least one of the pixel locations includes a bar of pixels along a section of a column or row of the digital image, and correcting the geometrical distortion includes implanting the dummy pixels in the bar. In yet other embodiments, at least another of the pixel locations includes an additional bar of pixels located along an additional section of the row or column, and correcting the geometrical distortion includes implanting the dummy pixels in the additional bar.

In an embodiment, implanting the dummy pixels includes shifting the additional section relative to the section. In another embodiment, the digital image includes at least first and second colors, and correcting the geometric distortion includes correcting a difference between printed first and second widths of the first and second colors, respectively. In yet another embodiment, correcting the geometric distortion includes compensating for a trapeze shape of a print of the digital image.

In some embodiments, estimating the geometric distortion includes comparing at least part of the printed image with a reference image. In other embodiments, the method includes, based on the digital image, qualifying or disqualifying at least one of the printed image and a print of the subsequent digital image. In yet other embodiments, the method includes, based on the digital image, estimating at least an additional geometric distortion of the printed image relative to a source image used for printing the printed image.

In an embodiment, the additional geometric distortion includes a tilt of the printed image relative to the source image, and the method includes, correcting the tilt by applying, to the source image, a pre-compensation for the tilt. In another embodiment, the additional geometric distortion includes a color to color position difference between first and second colors of the printed image, and the method includes correcting the color to color position difference by shifting, in the subsequent digital image, at least one of the first and second colors. In yet another embodiment, the digital image includes at least first and second color images, and the method includes aligning an edge of the first and second color images to one another by shifting the edge of the second color image to align with the edge of the first color image.

In some embodiments, the digital image includes multiple color images, and implanting the one or more dummy pixels includes, for a given dummy pixel at a given pixel location in a given color image, setting a waveform that determines a size of the given dummy pixel based on one or more selected pixels adjacent to the given pixel location, and printing the subsequent digital image includes printing the given dummy pixel in accordance with the waveform. In other embodiments, the digital image includes multiple registration marks, and estimating the geometric distortion includes analyzing the geometric distortion between the registration marks.

In an embodiment, the digital image includes registration marks in at least one of: (i) a margin of the digital image and (ii) an interior of the digital image. In another embodiment, at least two of the registration marks include a bar of the registration marks arranged along a section of a column of the digital image.

There is additionally provided, in accordance with an embodiment of the present invention, an apparatus for correcting distortion in image printing, the apparatus includes an interface and a processor. The interface is configured to receive a digital image acquired from a printed image. The processor is configured to: (a) estimate, based on the digital image, a geometric distortion in the printed image, (b) calculate one or more pixel locations that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion, and (c) correct the geometric distortion in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image.

There is additionally provided, in accordance with an embodiment of the present invention, a system including a processor and a printing subsystem. The processor is configured to: (a) receive a digital image acquired from a printed image, (b) estimate, based on the digital image, a geometric distortion in the printed image, (c) calculate one or more pixel locations that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion, and (d) correct the geometric distortion in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image. The printing subsystem is configured to print the subsequent digital image having the corrected geometric distortion.

There is further provided, in accordance with an embodiment of the present invention, a computer software product, the product including a tangible non-transitory computer-readable medium, in which program instructions are stored, which instructions, when read by a processor, cause the processor to: (a) receive a digital image acquired from a printed image, (b) estimate, based on the digital image, a geometric distortion in the printed image, (c) calculate one or more pixel locations that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion, and (d) correct the geometric distortion in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image.

There is additionally provided, in accordance with an embodiment of the present invention, a printing system including a printing subsystem and a processor. The printing subsystem includes an intermediate transfer member (ITM) configured to receive ink droplets from an image forming station to form an ink image thereon, and to form a printed image by transferring the ink image to a target substrate. The processor is configured to: (a) receive a digital image acquired from the printed image, (b) estimate, based on the digital image, a geometric distortion in the printed image, (c) calculate one or more pixel locations that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion, and (d) correct the geometric distortion in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image. The printing subsystem is configured to print the subsequent digital image having the corrected geometric distortion.

There is further provided, in accordance with an embodiment of the present invention, a method for correcting distortion in image printing, the method including printing a printed image by applying, to an intermediate transfer member (ITM), ink droplets from an image forming station to form an ink image thereon, and transferring the ink image from the ITM to a target substrate. A digital image that is acquired from the printed image, is received. Based on the digital image, a geometric distortion is estimated in the printed image. One or more pixel locations are calculated, such that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion. The geometric distortion is corrected in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image. The subsequent digital image having the corrected geometric distortion, is printed.

There is additionally provided, in accordance with an embodiment of the present invention, a method for correcting distortion in image printing, the method including receiving a digital image acquired from a printed image. Based on the digital image, a geometric distortion is estimated in the printed image. One or more pixel locations are calculated, such that, when one or more given pixels are removed from the digital image, compensate for the estimated geometric distortion. The geometric distortion is corrected in a subsequent digital image to be printed, by removing the one or more given pixels at the one or more calculated pixel locations in the subsequent digital image. The subsequent digital image having the corrected geometric distortion, is printed.

There is additionally provided, in accordance with an embodiment of the present invention, a system including a processor and a printing subsystem. The processor is configured to: (a) receive a digital image acquired from a printed image, (b) estimate, based on the digital image, a geometric distortion in the printed image, (c) calculate one or more pixel locations that, when one or more given pixels are removed from the digital image, compensate for the estimated geometric distortion, and (d) correct the geometric distortion in a subsequent digital image to be printed, by removing the one or more given pixels at the one or more calculated pixel locations in the subsequent digital image. The printing subsystem is configured to print the subsequent digital image having the corrected geometric distortion.

The present invention will be more fully understood from the following detailed description of the embodiments thereof, taken together with the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic side view of a digital printing system, in accordance with an embodiment of the present invention;

Fig. 2A is a schematic, pictorial illustration of a process sequence for correcting distortions in an image printed in a digital printing system, in accordance with an embodiment of the present invention;

Fig. 2B is a flow chart that schematically illustrates a method for correcting distortions in digital printing, in accordance with an embodiment of the present invention;

Fig. 3 is a schematic, pictorial illustration of a method for calculating a shift matrix in an image to be printed in a digital printing system, in accordance with an embodiment of the present invention;

Fig. 4 is a schematic, pictorial illustration of a method for calculating a count matrix for implanting dummy pixels in an image to be printed in a digital printing system, in accordance with an embodiment of the present invention;

Fig. 5 is a schematic, pictorial illustration of a method for implanting dummy pixels in an image to be printed in a digital printing system, in accordance with an embodiment of the present invention;

Fig. 6 is a schematic, pictorial illustration of a method for setting pixel locations in a digital image to be printed in a digital printing system, in accordance with an embodiment of the present invention;

Fig. 7 is a schematic, pictorial illustration of a method for setting pixel locations in a digital image to be printed in a digital printing system, in accordance with another embodiment of the present invention; and

Fig. 8 is a schematic, pictorial illustration of a method for aligning an implanted image to be printed in a digital printing system, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

OVERVIEW

Embodiments of the present invention that are described hereinbelow provide methods and apparatus for correcting distortions in printing of a digital image. In some embodiments, a digital printing system comprises a flexible intermediate transfer member (ITM) configured to receive an ink image and to move along an axis, referred to herein as an X axis, to an impression station so as to transfer the ink image to a target substrate, such as a paper sheet.

The printed image may have geometric distortions along the X axis that change with the position on a Y axis (orthogonal to the X axis), referred to herein as wave X(Y), and/or distortions along the Y axis that change with the position on the X axis, referred to herein as wave Y(X).

The wave Y(X) distortion may be caused by multiple sources, such as bending and stretching of the ITM, deviation from the specified velocity at the impression station, misalignment between color images, also referred to herein as "bar to bar position delta," and different widths of similar features among the different color images referred to herein as "bar to bar width delta" or as "color to color width difference." The digital image may have additional distortions, such as trapeze shape, tilt, skew, and displacement of the digital image relative to the substrate, for example in Y axis, also referred to herein as "image to substrate Y" (Im2SubY).

In some embodiments, the digital printing system comprises a processor configured to receive a digital image acquired from a printed image. The printed image was printed by the digital printing system as a composition of multiple color images such as cyan, magenta, yellow and black. The processor is configured to estimate, based on the digital image, one or more types of the geometric distortions described above, to apply, to the distorted digital image, shifting of pixels and implanting of synthetic pixels, also referred to herein as "dummy pixels" so as to compensate for the distortions, and to produce a subsequent digital image that corrects the geometric distortion. In some embodiments, the subsequent digital image is printed and an additional digital image is acquired so as to check whether the distortions have indeed been corrected.

In some embodiments, the digital image comprises registration marks located at first (e.g., left) and second (e.g., right) opposite edges along the Y axis of the digital image. The registration marks are indicative of at least some of the distortions described above. In some embodiments, the processor is configured to identify, based on the distorted registration marks, at least some of the distortions in the digital image and to apply, to one or more of the color images, a linear offset and/or non-linear shifting so as to compensate for various distortions, such as, tilt, skew, Im2SubY and other wavy articles.

In some embodiments, the processor is further configured to identify, based on the distorted registration marks at the first end, bar to bar position delta distortions between the different color images, and to shift at least one of the color images so as to align the first end of all the color images.

Subsequently, the processor identifies, based on the registration marks at the second end, distortions of the bar to bar width delta between the color images, and calculates, at one or more of the color images, pixel locations and the amount of dummy pixels implanted therein so as to compensate for the bar to bar width delta between the color images (which may also vary along X axis, per color).

The disclosed techniques improve the quality of printed digital images by compensating for a large variety of distortions. Moreover, the disclosed techniques reduce waste of substrate and ink by improving the yield of the printed substrates.

SYSTEM DESCRIPTION

Fig. 1 is a schematic side view of a digital printing system 10, in accordance with an embodiment of the present invention. In some embodiments, system 10 comprises a rolling flexible blanket 44 that cycles through an image forming station 60, a drying station 64, an impression station 84 and a blanket treatment station 52. In the context of the present invention and in the claims, the terms "blanket" and "intermediate transfer member (ITM)" are used interchangeably and refer to a flexible member comprising one or more layers used as an intermediate member configured to receive an ink image and to transfer the ink image to a target substrate, as will be described in detail below.

In an operative mode, image forming station 60 is configured to form a mirror ink image, also referred to herein as "an ink image" (not shown), of a digital image 42 on an upper run of a surface of blanket 44. Subsequently the ink image is transferred to a target substrate, (e.g., a paper, a folding carton, or any suitable flexible package in a form of sheets or continuous web) located under a lower run of blanket 44.

In the context of the present invention, the term "run" refers to a length or segment of blanket 44 between any two given rollers over which blanket 44 is guided.

In some embodiments, during installation blanket 44 may be adhered edge to edge to form a continuous blanket loop (not shown). An example of a method and a system for the installation of the seam is described in detail in U.S. Provisional Application 62/532,400, whose disclosure is incorporated herein by reference.

In some embodiments, image forming station 60 typically comprises multiple print bars 62, each mounted (e.g., using a slider) on a frame (not shown) positioned at a fixed height above the surface of the upper run of blanket 44. In some embodiments, each print bar 62 comprises a strip of print heads as wide as the printing area on blanket 44 and comprises individually controllable print nozzles.

In some embodiments, image forming station 60 may comprise any suitable number of bars 62, each bar 62 may contain a printing fluid, such as an aqueous ink of a different color. The ink typically has visible colors, such as but not limited to cyan, magenta, red, green, blue, yellow, black and white. In the example of Fig. 1, image forming station 60 comprises seven print bars 62, but may comprise, for example, four print bars 62 having any selected colors such as cyan, magenta, yellow and black.

In some embodiments, the print heads are configured to jet ink droplets of the different colors onto the surface of blanket 44 so as to form the ink image (not shown) on the surface of blanket 44.

In some embodiments, different print bars 62 are spaced from one another along the movement axis of blanket 44, represented by an arrow 94. In this configuration, accurate spacing between bars 62, and synchronization between directing the droplets of the ink of each bar 62 and moving blanket 44 are essential for enabling correct placement of the image pattern.

In the context of the present disclosure and in the claims, the terms "inter-color pattern placement," "pattern placement accuracy," color-to-color registration," "C2C registration" "bar to bar registration," and "color registration" are used interchangeably and refer to any placement accuracy of two or more colors relative to one another.

In some embodiments, system 10 comprises heaters, such as hot gas or air blowers 66, which are positioned in between print bars 62, and are configured to partially dry the ink droplets deposited on the surface of blanket 44. This hot air flow between the print bars may assist, for example, in reducing condensation at the surface of the print heads and/or in handling satellites (e.g., residues or small droplets distributed around the main ink droplet), and/or in preventing blockage of the inkjet nozzles of the print heads, and/or in preventing the droplets of different color inks on blanket 44 from undesirably merging into one another. In some embodiments, system 10 comprises a drying station 64, configured to blow hot air (or another gas) onto the surface of blanket 44. In some embodiments, drying station comprises air blowers 68 or any other suitable drying apparatus.

In drying station 64, the ink image formed on blanket 44 is exposed to radiation and/or to hot air in order to dry the ink more thoroughly, evaporating most or all of the liquid carrier and leaving behind only a layer of resin and coloring agent which is heated to the point of being rendered tacky ink film.

In some embodiments, system 10 comprises a blanket module 70 comprising a rolling ITM, such as a blanket 44. In some embodiments, blanket module 70 comprises one or more rollers 78, wherein at least one of rollers 78 comprises an encoder (not shown), which is configured to record the position of blanket 44, so as to control the position of a section of blanket 44 relative to a respective print bar 62. In some embodiments, the encoder of roller 78 typically comprises a rotary encoder configured to produce rotary-based position signals indicative of an angular displacement of the respective roller.

Additionally or alternatively, blanket 44 may comprise an integrated encoder (not shown) for controlling the operation of various modules of system 10. The integrated encoder is described in detail, for example, in U.S. Provisional Application 62/689,852, whose disclosure is incorporated herein by reference.

In some embodiments, blanket 44 is guided over rollers 76 and 78 and a powered tensioning roller, also referred to herein as a dancer 74. Dancer 74 is configured to control the length of slack in blanket 44 and its movement is schematically represented by a double sided arrow. Furthermore, any stretching of blanket 44 with aging would not affect the ink image placement performance of system 10 and would merely require the taking up of more slack by tensioning dancer 74.

In some embodiments, dancer 74 may be motorized. The configuration and operation of rollers 76 and 78, and dancer 74 are described in further detail, for example, in U.S. Patent Application Publication 2017/0008272 and in the above-mentioned PCT International Publication WO 2013/132424, whose disclosures are all incorporated herein by reference.

In impression station 84, blanket 44 passes between an impression cylinder 82 and a pressure cylinder 90, which is configured to carry a compressible blanket.

In some embodiments, system 10 comprises a control console 12, which is configured to control multiple modules of system 10, such as blanket module 70, image forming station 60 located above blanket module 70, and a substrate transport module 80 located below blanket module 70.

In some embodiments, console 12 comprises a processor 20, typically a general-purpose computer, with suitable front end and interface circuits for interfacing with a controller 54, via a cable 57, and for receiving signals therefrom. In some embodiments, controller 54, which is schematically shown as a single device, may comprise one or more electronic modules mounted on system 10 at predefined locations. At least one of the electronic modules of controller 54 may comprise an electronic device, such as control circuitry or a processor (not shown), which is configured to control various modules and stations of system 10. In some embodiments, processor 20 and the control circuitry may be programmed in software to carry out the functions that are used by the printing system, and store data for the software in a memory 22. The software may be downloaded to processor 20 and to the control circuitry in electronic form, over a network, for example, or it may be provided on non-transitory tangible media, such as optical, magnetic or electronic memory media.

In some embodiments, console 12 comprises a display 34, which is configured to display data and images received from processor 20, or inputs inserted by a user (not shown) using input devices 40. In some embodiments, console 12 may have any other suitable configuration, for example, an alternative configuration of console 12 and display 34 is described in detail in U.S. Patent 9,229,664, whose disclosure is incorporated herein by reference.

In some embodiments, processor 20 is configured to display on display 34, a digital image 42 comprising one or more segments (not shown) of image 42 and various types of test patterns (described in detail below) stored in memory 22.

In some embodiments, blanket treatment station 52, also referred to herein as a cooling station, is configured to treat the blanket by, for example, cooling it and/or applying a treatment fluid to the outer surface of blanket 44, and/or cleaning the outer surface of blanket 44. At blanket treatment station 52 the temperature of blanket 44 can be reduced to a desired value before blanket 44 enters image forming station 60. The treatment may be carried out by passing blanket 44 over one or more rollers or blades configured for applying cooling and/or cleaning and/or treatment fluid on the outer surface of the blanket. In some embodiments, processor 20 is configured to receive, e.g., from temperature sensors (not shown), signals indicative of the surface temperature of blanket 44, so as to monitor the temperature of blanket 44 and to control the operation of blanket treatment station 52. Examples of such treatment stations are described, for example, in PCT International Publications WO 2013/132424 and WO 2017/208152, whose disclosures are all incorporated herein by reference.

Additionally or alternatively, treatment fluid may be applied by jetting, prior to the ink jetting at the image forming station.

In the example of Fig. 1, station 52 is mounted between roller 78 and roller 76, yet, station 52 may be mounted adjacent to blanket 44 at any other suitable location between impression station 84 and image forming station 60.

In the example of Fig. 1, impression cylinder 82 impresses the ink image onto the target flexible substrate, such as an individual sheet 50, conveyed by substrate transport module 80 from an input stack 86 to an output stack 88 via impression cylinder 82.

In some embodiments, the lower run of blanket 44 selectively interacts at impression station 84 with impression cylinder 82 to impress the image pattern onto the target flexible substrate compressed between blanket 44 and impression cylinder 82 by the action of pressure of pressure cylinder 90. In the case of a simplex printer (i.e., printing on one side of sheet 50) shown in Fig. 1, only one impression station 84 is needed.

In other embodiments, module 80 may comprise two impression cylinders so as to permit duplex printing. This configuration also enables conducting single sided prints at twice the speed of printing double sided prints. In addition, mixed lots of single and double sided prints can also be printed. In alternative embodiments, a different configuration of module 80 may be used for printing on a continuous web substrate. Detailed descriptions and various configurations of duplex printing systems and of systems for printing on continuous web substrates are provided, for example, in U.S. patents 9,914,316 and 9,186,884, in PCT International Publication WO 2013/132424, in U.S. Patent Application Publication 2015/0054865, and in U.S. Provisional Application 62/596,926, whose disclosures are all incorporated herein by reference.

As briefly described above, sheets 50 or continuous web substrate (not shown) are carried by module 80 from input stack 86 and pass through the nip (not shown) located between impression cylinder 82 and pressure cylinder 90. Within the nip, the surface of blanket 44 carrying the ink image is pressed firmly, e.g., by compressible blanket (not shown), of pressure cylinder 90 against sheet 50 (or other suitable substrate) so that the ink image is impressed onto the surface of sheet 50 and separated neatly from the surface of blanket 44. Subsequently, sheet 50 is transported to output stack 88.

In the example of Fig. 1, rollers 78 are positioned at the upper run of blanket 44 and are configured to maintain blanket 44 taut when passing adjacent to image forming station 60. Furthermore, it is particularly important to control the speed of blanket 44 below image forming station 60 so as to obtain accurate jetting and deposition of the ink droplets, thereby placement of the ink image, by forming station 60, on the surface of blanket 44.

In some embodiments, impression cylinder 82 is periodically engaged to and disengaged from blanket 44 to transfer the ink images from moving blanket 44 to the target substrate passing between blanket 44 and impression cylinder 82. In some embodiments, system 10 is configured to apply torque to blanket 44 using the aforementioned rollers and dancers, so as to maintain the upper run taut and to substantially isolate the upper run of blanket 44 from being affected by any mechanical vibrations occurred in the lower run.

In some embodiments, system 10 comprises an image quality control station 55, also referred to herein as an automatic quality management (AQM) system, which serves as a closed loop inspection system integrated in system 10. In some embodiments, station 55 may be positioned adjacent to impression cylinder 82, as shown in Fig. 1, or at any other suitable location in system 10.

In some embodiments, station 55 comprises a camera (not shown), which is configured to acquire one or more digital images of the aforementioned ink image printed on sheet 50. In some embodiments, the camera may comprises any suitable image sensor, such as a Contact Image Sensor (CIS) or a Complementary metal oxide semiconductor (CMOS) image sensor, and a scanner comprising a slit having a width of about one meter or any other suitable width.

In some embodiments, station 55 may comprise a spectrophotometer (not shown) configured to monitor the quality of the ink printed on sheet 50.

In some embodiments, the digital images acquired by station 55 are transmitted to a processor, such as processor 20 or any other processor of station 55, which is configured to assess the quality of the respective printed images. Based on the assessment and signals received from controller 54, processor 20 is configured to control the operation of the modules and stations of system 10. In the context of the present invention and in the claims, the term "processor" refers to any processing unit, such as processor 20 or any other processor connected to or integrated with station 55, which is configured to process signals received from the camera and/or the spectrophotometer of station 55. Note that the signal processing operations, control-related instructions, and other computational operations described herein may be carried out by a single processor, or shared between multiple processors of one or more respective computers.

In some embodiments, station 55 is configured to inspect the quality of the printed images and test pattern so as to monitor various attributes, such as but not limited to full image registration with sheet 50, color-to-color registration, printed geometry, image uniformity, profile and linearity of colors, and functionality of the print nozzles. In some embodiments, processor 20 is configured to automatically detect geometrical distortions or other errors in one or more of the aforementioned attributes. For example, processor 20 is configured to compare between a design version (also referred to herein as a source image) of a given digital image and a digital image of the printed version of the given image, which is acquired by the camera.

In other embodiments, processor 20 may apply any suitable type image processing software, e.g., to a test pattern, for detecting distortions indicative of the aforementioned errors. In some embodiments, processor 20 is configured to analyze the detected distortion in order to apply a corrective action to the malfunctioning module, and/or to feed instructions to another module or station of system 10, so as to compensate for the detected distortion.

In some embodiments, by acquiring images of the testing marks printed at the bevels of sheet 50, station 55 is configured to measure various types of distortions, such as C2C registration, image-to-substrate registration, different width between colors referred to herein as "bar to bar width delta" or as "color to color width difference", various types of local distortions, and front-to-back registration errors (in duplex printing). In some embodiments, processor 20 is configured to: (i) sort out, e.g., to a rejection tray (not shown), sheets 50 having a distortion above a first predefined set of thresholds, (ii) initiate corrective actions for sheets 50 having a distortion above a second, lower, predefined set of threshold, and (iii) output sheets 50 having minor distortions, e.g., below the second set of thresholds, to output stack 88.

In some embodiments, processor 20 is further configured to detect, e.g., by analyzing a pattern of the printed inspection marks, additional geometric distortion such as scaling up or down, skew, or a wave distortion formed in at least one of an axis parallel to and an axis orthogonal to the movement axis of blanket 44 as will be described in detail in Figs. 2A, 2B, and 3-8 below.

In some embodiments, processor 20 is configured to analyze the signals acquired by station 55 so as to monitor the nozzles of image forming station 60. By printing a test pattern of each color of station 60, processor 20 is configured to identify various types of defects indicative of malfunctions in the operation of the respective nozzles.

For example, absence of ink in a designated location in the test pattern is indicative of a missing or blocked nozzle. A shift of a printed pattern (relative to the original design, also referred to herein as a source image) is indicative of inaccurate positioning of a respective print bar 62 or of one or more nozzles of the respective print bar. Non-uniform thickness of a printed feature of the test pattern is indicative of width differences between respective print bars 62, referred to above as bar to bar width delta.

In some embodiments, processor 20 is configured to detect, based on signals received from the spectrophotometer of station 55, deviations in the profile and linearity of the printed colors.

In some embodiments, processor 20 is configured to detect, based on the signals acquired by station 55, various types of defects: (i) in the substrate (e.g., blanket 44 and/or sheet 50), such as a scratch, a pin hole, and a broken edge, and (ii) printing-related defects, such as irregular color spots, satellites, and splashes.

In some embodiments, processor 20 is configured to detect these defects by comparing between a section of the printed and a respective reference section of the original design, also referred to herein as a master or a source image. Processor 20 is further configured to classify the defects, and, based on the classification and predefined criteria, to reject sheets 50 having defects that are not within the specified predefined criteria.

In some embodiments, the processor of station 55 is configured to decide whether to stop the operation of system 10, for example, in case the defect density is above a specified threshold. The processor of station 55 is further configured to initiate a corrective action in one or more of the modules and stations of system 10, as described above. The corrective action may be carried out on-the-fly (while system 10 continue the printing process), or offline, by stopping the printing operation and fixing the problem in a respective modules and/or station of system 10. In other embodiments, any other processor or controller of system 10 (e.g., processor 20 or controller 54) is configured to start a corrective action or to stop the operation of system 10 in case the defect density is above a specified threshold.

Additionally or alternatively, processor 20 is configured to receive, e.g., from station 55, signals indicative of additional types of defects and problems in the printing process of system 10. Based on these signals processor 20 is configured to automatically estimate the level of pattern placement accuracy and additional types of defects not mentioned above. In other embodiments, any other suitable method for examining the pattern printed on sheets 50 (or on any other substrate described above), can also be used, for example, using an external (e.g., offline) inspection system, or any type of measurements jig and/or scanner. In these embodiments, based on information received from the external inspection system, processor 20 is configured to initiate any suitable corrective action and/or to stop the operation of system 10.

The configuration of system 10 is simplified and provided purely by way of example for the sake of clarifying the present invention. The components, modules and stations described in printing system 10 hereinabove and additional components and configurations are described in detail, for example, in U.S. Patents 9,327,496 and 9,186,884, in PCT International Publications WO 2013/132438, WO 2013/132424 and WO 2017/208152, in U.S. Patent Application Publications 2015/0118503 and 2017/0008272, whose disclosures are all incorporated herein by reference.

The particular configurations of system 10 is shown by way of example, in order to illustrate certain problems that are addressed by embodiments of the present invention and to demonstrate the application of these embodiments in enhancing the performance of such systems. Embodiments of the present invention, however, are by no means limited to this specific sort of example systems, and the principles described herein may similarly be applied to any other sorts of printing systems.

CORRECTING DISTORTIONS IN A DIGITAL IMAGE AS WAS PRINTED BY A DIGITAL PRINTING SYSTEM

Fig. 2A is a schematic, pictorial illustration of a process sequence for correcting distortions in a digital image 200 to be printed in system 10, in accordance with an embodiment of the present invention. In the example of Fig. 2A, image 200 comprises two color images and therefore may replace, for example, a subset of image 42 of Fig. 1 above.

Note that the description of Fig. 2A is an overview of the entire process sequence and therefore the steps are described briefly. Detailed description of each step are provided in Figs. 2B and 3-8 below. The disclosed techniques are applied to correct various types of distortions, such as local distortions and continuous wave distortions described herein.

WAVE DISTORTION

The phenomena of wave distortion is caused by various errors, such as but not limited to (i) erroneous positioning of one or more print bars 62 in image forming station 60 (ii) deviation from the specified motion profile of blanket 44, and (iii) deviation from the specified relative velocity between blanket 44 and sheet 50 at impression station 84. As described above, print bars 62 are positioned at a predefined distance from one another along the movement axis of blanket 44, which is represented by arrow 94 and also referred to herein as X axis. Each print bar 62 is mounted on the frame on an axis orthogonal to arrow 94, referred to herein as Y axis.

The distortions described above, and additional errors, may result in a wavy pattern of the printed features. Note that typically the wavy pattern has two components: (i) a common wave of all colors, e.g., due to the aforementioned deviation at impression station 84, and (ii) different waves formed in each color image are caused, for example, by the erroneous positioning of one or more print bars 62 and/or due to temporary variation in the velocity of blanket 44, for example, when the upper run passes between the black and the cyan print bars.

Additional types of distortions may cause deviation of the printed width between bars, also referred to as bar to bar width delta, and/or shift (e.g., in Y axis) of the position of the droplets jetted by at least one bar, also referred to herein as "bar to bar Y position delta" or as "color to color position difference." Based on the above, the wave distortion has two components, distortion along X axis that changes with the position on Y axis, referred to herein as wave X(Y), and distortion along Y axis that changes with the position on X axis, referred to herein as wave Y(X). Further details about the distortion and correction of waves X(Y) and Y(X) are depicted in Figs. 2A, 2B and 3-8 below.

COMPENSATING FOR THE LOCAL AND WAVE DISTORTIONS

The process sequence for correcting the wave distortion begins with a schematic illustration of digital image 200. As described in Fig. 1 above, module 55 acquires a digital image from an image printed by system 10. As mentioned above, image 200 is a subset of the acquired digital image for having two colors, e.g., a magenta image 202 shown as a dashed-line polygon, and a cyan image 204 shown as a solid-line polygon. Embodiments of the present invention that are described below, depict distortion and correction processes carried out only in the cyan and magenta colors for the sake of conceptual clarity. However, the same embodiments are applicable for any number of colors described, for example, in Fig. 1 above.

In the example distortion shown in image 200, images 202 and 204 have, relative to one another, bar to bar position delta in Y axis, and bar to bar width delta. In addition, at least one of images 202 and 204 has one or more additional distortions, such as (a) a trapeze-shape, (b) tilt, (c) a displacement in Y axis relative to the substrate (e.g., sheet 50), also referred to herein as Im2SubY, and (d) a displacement of a given color in X axis relative to any suitable reference, e.g., another color, also referred to herein as bar to bar Y position delta.

In some embodiments, at a step 1 processor 20 applies, to at least one of images 202 and 204, a linear offset and/or a non-linear shifting so as to compensate for part of the wave Y(X) distortion caused, for example, by bending and stretching of the flexible ITM and from deviation from the specified velocity at impression station 84.

In some embodiments, processor 20 is configured to estimate, based on image 200 and relative to the source image mentioned in Fig. 1 above, at least an additional geometric distortion of the printed image that is used for printing the printed image. The additional geometric distortion may comprise, for example, a tilt of the printed image relative to the source image. In such embodiments, processor 20 is configured to correct the tilt by applying, to the source image, a pre-compensation for the tilt. Processor 20 is further configured to compensate for the tilt and Im2SubY in any of images 202 and 204 using linear offset or any other suitable technique. Note that the shifting and offset carried out at step 1, which are represented by arrows 212, may differ along left ends 208 and 210 also referred to herein as left edges, which are located at the left edge of respective images 202 and 204, as shown by the non-uniform length of arrows 212.

In an embodiment, at a step 2 processor 20 corrects the bar to bar Y position delta between the respective magenta and cyan print bars. In this embodiment, processor 20 shifts images 202 and 204 relative to one another, as shown by arrows 220 having similar length, thereby aligning respective ends 208 and 210 with one another. In some embodiments, processor 20 may select, among all color images, a reference image as the image mostly shifted along Y axis. In the example of step 1, end 208 serves as a reference so that end 210 is shifted in the direction of arrow 94, also referred to herein as the right direction.

In some embodiments, processor 20 is configured to carry out steps 1 and 2 simultaneously. In other embodiments, steps 1 and 2 may be carried out sequentially, in the order described above, or in a reversed order in which step 2 is carried out before step 1. After concluding steps 1 and 2, magenta image 202 and cyan image 204 are aligned at respective ends 208 and 210, yet, other ends, such as respective ends 222 and 224 are not aligned due to a geometric distortion, such as bar to bar width delta between cyan image 204 and magenta image 202. The bar to bar width delta may also appear as a trapeze shape or as a trapeze additionally distorted by other types of linear and/or non-linear distortions, or as a distortion having any other type of linear or non-linear shape, of at least one of images 202 and 204 as shown at step 2.

In some embodiments, at a step 3 processor 20 identifies, based on image 200, which color image among images 202 and 204 has the largest print bar width. In other words, the processor identifies which print bar 62 is jetting droplets that eventually print the broadest pixels or pixel bars.

As shown at step 2, the dashed line of magenta image 202 has the largest width among all colors images. Note that in the example of Fig. 2A there are only two colors, but in real-life there are typically 4-7 color images, from which the magenta image has the largest width. In an embodiment, the image having the largest print bar width may serve as a reference for all other colors, each of which has a distortion relative to the reference image. In the example of Fig. 2A, magenta image 202 serves as the reference. In this embodiment, based on the color images of step 2, processor 20 estimates the geometric distortion of cyan image 204 relative to magenta image 202.

In some embodiments, processor 20 is configured to calculate, at image 204, one or more pixel locations 228, such that when one or more dummy pixels are implanted in the cyan image at locations 228, the implanted dummy pixels compensate for the estimated geometric distortion of cyan image 204 relative to magenta image 202. As shown at step 3, the dummy pixels are implanted at pixel locations 228 so as to compensate for the geometric distortion of cyan image 202. As a result of the dummy pixel implantation, end 224 of cyan image 204 is moved towards end 222 of magenta image 202, and eventually is aligned therewith.

After implanting the dummy pixels at locations 228, images 202 and 204 are aligned with one another, but have a trapeze shape or any other shape formed, initially by the bar to bar width delta and other distortions, and subsequently, by the implanted dummy pixels at pixel locations 228.

In some embodiments, at a step 4, processor 20 is configured to calculate one or more shape-correcting locations 230, such that when one or more dummy pixels 232 and 234 are implanted in respective images 202 and 204 at locations 230, the increased width of the implanted dummy pixels compensates for the trapeze distortion and converts the trapeze shape of images 202 and 204 to a rectangular or parallelogram shape. As shown at steps 3 and 4, the dummy pixels may be implanted as a bar of pixels along a section of a column of images 202 and 204. The implantation pixel bars will be described in more details in Figs. 6 and 7 below.

Similarly to the sequence described at steps 1 and 2 above, processor 20 is configured to carry out steps 3 and 4 simultaneously. In other embodiments, steps 3 and 4 may be carried out sequentially, in the order described above, or in a reversed order. In the example embodiment of Fig. 2A the left end (e.g., ends 208 and 210) of images 202 and 204 is set as an anchor, whereas the right end (e.g., ends 222 and 224) of images 202 and 204 is moved due to the implantation so as to compensate for the bar to bar width delta causing the trapeze distortion and the wave Y(X).

In this embodiment, the shifts described at steps 1 and 2, and the implants described at steps 3 and 4 are performed from left to right. In other embodiments, the shifting and implanting steps may be carried out in any suitable direction, for example, at step 1 end 208 is shifted to the left side so as to be aligned with end 210.

Additionally or alternatively, the shifting and implanting steps may be carried out vertically at any suitable direction, so as to compensate for distortions. For example, the upper ends of images 202 and 204 may be aligned after steps 1 and 2, and the lower ends of images 202 and 204 are moved as a result of the dummy pixels implanting processes carried out at steps 3 and 4.

In alternative embodiments of steps 3 and 4, the dummy pixels may be implanted as a bar of pixels along a section of a row of images 202 and 204. Furthermore, the implanting of the bar of pixels described above, may be carried out along a section of a column and/or a row of the digital image, such that the compensation for the distortion may be carried out in one axis or in two axes (e.g., X and Y) simultaneously or sequentially.

In other embodiments, the pixels locations may be arranged using any other suitable configuration, for example, in a diagonal line geometry, or in a staircase.

In some embodiments, at a step 5 that concludes the process sequence for correcting the distortions in image 200, a set of scaling and shifting operations are carried out on images 202 and 204 so as to compensate for additional sources of wave X(Y) distortion and to align the magenta and cyan images relative to sheet 50 by correcting their displacements in Y axis (i.e., Im2SubY) and/or in X axis relative to sheet 50.

Fig. 2B is a flow chart that schematically illustrates a method 250 for correcting distortions in digital printing, in accordance with an embodiment of the present invention. Method 250 begins at a digital image receiving step 252, with processor 20 receiving digital image 200, having color images 202 and 204, acquired from a printed image, which was printed by system 10 on sheet 50.

At a distortion estimation step 254, processor 20 estimates, based on digital image 200, a geometrical distortion in the printed image, as described in the raw image of Fig. 2A above. At a shifting step 256, processor 20 applies offset and/or non-linear shift to at least one of images 202 and 204, so as to align ends 208 and 210 with one another and to correct bar to bar Y position delta (and optionally other distortions), as described, respectively, in steps 1 and 2 of Fig. 2A above. Note that processor 20 is configured to carry out step 256 simultaneously or in two different steps (e.g., steps 1 and 2 of Fig. 2A above).

At a pixel location calculation step 258, processor 20 calculates one or more pixel locations (e.g., pixel locations 228 of Fig. 2A above) that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion. At a distortion correction step 260, processor 20 corrects the geometrical distortion by implanting the dummy pixels in a subsequent digital image. As described in steps 3 and 4 of Fig. 2A above, the dummy pixels may also be implanted as a bar of pixels along a section of a column of images 202 and 204.

At a printing step 262 that concludes method 250, system 10 receives printing instructions from processor 20 and prints the subsequent digital image having the corrected distortion, as described in step 5 of Fig. 2A above.

Fig. 3 is a schematic, pictorial illustration of a method for calculating a shift matrix in an image 306 to be printed in system 10, in accordance with an embodiment of the present invention. Image 306 may replace, for example, image 42 of Fig. 1 above, and the method may replace steps 1 and 2 of Fig. 2A. In the example of Fig. 3, the term “right” is defined in the direction of arrow 94, and the term “left” is defined in the opposite direction.

The method begins with a printed frame 300, which comprises image 306 and testing sides 302 and 304 located adjacent to image 306, at the left and right margins of frame 300, respectively. In some embodiments, side 302 comprises five registration frames 310, 320, 330, 340 and 350 designed along testing side 302. In the example of Fig. 3, each registration frame comprises four registration marks 312, 314, 316 and 318 designed in four respective different colors, such as cyan (C), magenta (M), yellow (Y) and black (K). Note that a reference frame 301 represents the original design of the registration frames and marks of testing sides 302 and 306. In other embodiments, sites 302 and 306 may comprise any other suitable number of registration frames having, each, any suitable number of registration marks.

In some embodiments, frame 300 is printed on sheet 50 and subsequently, station 55 acquires and sends a digital format of frame 300 to processor 20 or to any other processor as described in Fig. 2A above. Note that frame 301 is not printed but only shown in Fig. 3 as a reference of the original design as described above. In the example of Fig. 3, black marks 318 are shifted more than all other mark, to the right, and marks 312 and 314 of frame 310 are shifted to the left.

In some embodiments, processor 20 inserts a constant offset to each registration mark so as to align marks 312, 314, 316 and 318 to a common position, e.g., at a center of gravity (COG) 303 of frame 301. Processor 20 is further configured to produce, based on the registration frames and registration marks, a set of interpolated curves between the respective marks of each color, for example between marks 312 of frames 310, 320, 330, 340 and 350.

As described above, in the design of the registration frames there is a deliberate shift between the registration marks so that they will not be printed on top of one another. In some embodiment, processor 20 is configured to align the location of all the registration marks of each frame to the common position per the predetermined graphics offset, and subsequently, to determine which registration mark is shifted (e.g., relative to the COG).

The interpolated curves are referred to herein as wave profile curves representing the shift distortion occurred during the printing for each respective color of system 10. The term “wave profile curve” is also referred to below simply as “curve” for brevity.

In the example of Fig. 3 processor 20 produces four curves corresponding to the four registration marks: a cyan curve 362, a magenta curve 364, a yellow curve 366 and a black curve 368. In some embodiments, processor 20 is configured to calculate the compensating shift of the curves relative to a shift edge pixel, also referred to herein as a reference curve 360. As shown in Fig. 3, during the printing process black curve 368 has a shifting distortion to the right more than all other curves, and cyan curve 362 has a left shifting distortion relative to all other curves.

As described in Fig. 2A above, the shifting steps are compensating for the wave Y(X) distortion caused, for example, by bar to bar position delta. In an embodiment, processor 20 may set a target reference for aligning all curves thereto. For example, reference curve 360 may serve as a target reference.

In another embodiment, processor 20 may shift all curves to align with the rightmost curve (e.g., curve 368 in the example of Fig. 3) as shown at step 1 of Fig. 2A.

In some embodiments, processor 20 is configured to calculate, for each color image, a shift matrix that compensates for the shift distortion caused during the printing to each respective curve. Processor 20 is further configured to divide curve 360 to multiple sections that serve as correction strips 372A-372D such that the shift matrix comprises the calculated shift for each of the correction strip. In an embodiment, processor 20 is configured to set and use any suitable number of correction strips, each strip 372 may have any suitable size, which may be similar to or different from the size of the other strips.

In the example of Fig. 3, the calculated shift matrix has four curves 392, 394, 396 and 398 corresponding to curves 362, 364, 366 and 368. Note that curves 392, 394, 396 and 398 of the calculated shift matrix are shaped like a mirror image of the distorted curves, i.e., curves 362, 364, 366 and 368.

As shown in Fig. 2A above, after applying the shift matrix left ends 208 and 210 of the cyan and magenta images are aligned with one another. In the example of Fig. 3, processor 20 is configured to calculate a left end 370, which represents all the left ends of the cyan, magenta, yellow and black images, aligned with one another and with reference curve 360.

In other embodiments, an alternative method may be used for calculating the shift matrix in an image 376 to be printed in system 10. Image 376 may replace, for example, image 306 of frame 300, or image 42 of Fig. 1 above, and the alternative method may replace the method described in Fig. 3 above and/or steps 1 and 2 of FIG. 2A. The alternative method may be carried out using a printed frame 333, which may be used, for example, instead of printed frame 300 described above, and/or images 202 and 204 of FIG. 2A above.

In some embodiments, printed frame 333 comprises image 376 and at least three testing columns 373, 374 and 375. In some embodiments, testing columns 373 and 374, which are located, respectively, at the left and right margins of frame 333, may replace, for example, testing sides 302 and 304, respectively. In some embodiments, columns 373 and 374 may comprise, each, multiple registration frames, such as registration frames 310, 320, 330, 340 and 350. As described above, each registration frame may comprise four registration marks 312, 314, 316 and 318 designed in four respective different colors, such as C, M, Y and K, or any other suitable number of registration marks having any suitable respective colors and arranged in the registration frames using any suitable configuration.

In some embodiments, registration frame 333 may comprise one or more additional testing columns, such as testing column 375, disposed within the interior of image 376. Testing column 375 may comprise multiple registration frames, such as registration frames 310, 320, 330, 340 and 350 described above. In the example of frame 333, testing column 333 may divide image 376 into two sections, a section 377 between testing columns 373 and 375, and a section 378 between testing columns 375 and 374.

In some embodiments, frame 333 is printed on sheet 50 and subsequently, station 55 or any other imaging apparatus, acquires and sends a digital format of frame 333, e.g., to processor 20, as described in FIG. 2A above. Based on testing column 373, processor 20 inserts a constant offset to each registration mark so as to align marks 312, 314, 316 and 318, e.g., to COG 303. In addition, processor 20 produces, based on the registration frames and registration marks of testing column 373, a set of wave profile curves between the respective marks of each color.

In such embodiments, the wave profile curves represent the shift distortion occurred within section 377, during the printing of each color of system 10. Similarly, and using the same techniques, processor 20 produces, based on the registration frames and registration marks of testing column 375, a set of wave profile curves representing the shift distortion occurred for each color within section 378. In other words, by increasing the frequency of registration frames and marks within frame 333, processor 20 may increase the number of the produced wave profile curves. In the example of frame 300, processor 20 produces one set of profile curves 362, 364, 366 and 368 for the entire area of image 306. In the example of frame 333, however, by having testing column 375 processor 20 may improve the distortion correction resolution within image 376, by producing two respective sets of wave profile curves (such as curves 362, 364, 366 and 368) and two respective shift matrices (such as curves 392, 394, 396 and 398) for sections 377 and 378 of image 376.

The configuration of frame 333 is provided by way of example, in order to illustrate certain problems, such as correcting distortion in image printing, which are addressed by embodiments of the present invention and to demonstrate the application of these embodiments in enhancing the performance of system 10. Embodiments of the present invention, however, are by no means limited to this specific sort of example digital printing system, and the principles described herein may similarly be applied to other sorts of digital printing systems.

In other embodiments, frame 333 may comprise additional registration frames, such as registration frame 310, which may be disposed in image 376 using any suitable arrangement. In an example embodiment, frame 333 may comprise additional testing columns, such as testing column 375, disposed within the interior of image 376. For example, by having testing columns 373 and 374 at the left and right margins, and three testing columns disposed within the interior of image 376, processor 20 may produce four sets of wave profile curves and shift matrices for respective sections of image 376.

In other embodiments, frame 333 may comprise, in addition to or instead of any of testing columns 374-376, multiple registration frames, such as registration frame 310, which may be arranged across image 376 and the margins thereof, using any suitable configuration. In such embodiments, processor 20 may divide frame 333 to any suitable number of sections and may produce sets of wave profile curves and shift matrices for the respective number of sections of image 376.

CORRECTING WAVE Y(X) AND TRAPEZE DISTORTIONS BY IMPLANTING DUMMY PIXELS AT PREDEFINED PIXEL LOCATIONS

Fig. 4 is a schematic, pictorial illustration of a method for calculating a count matrix for implanting dummy pixels in image 306, in accordance with an embodiment of the present invention. The method described in Fig. 4 corresponds to step 3 of Fig. 2A above.

In some embodiments, the method begins with acquiring raw positions of registration frames 410, 420, 430, 440 and 450 located at side 304. Note that the raw positions are acquired by station 55 together with the acquisition of the corresponding frames of side 302 (e.g., frames 310, 320, 330, 340 and 350). Each frame of side 304 comprises marks 411, 413, 415 and 417 corresponding, by design, to marks 312, 314, 316 and 318 of registration frames 310, 320, 330, 340 and 350.

In some embodiments, processor 20 inserts a constant offset to each registration mark so as to align marks 411, 413, 415 and 417 to a common position using the same techniques described in Fig. 3 above. Subsequently, processor 20 produces, based on the registration frames and registration marks, a set of interpolated curves 382, 384, 386 and 388 (corresponding to curves 362, 364, 366 and 368 of Fig. 3 above) between the respective marks of each color.

In some embodiments, processor 20 applies the calculated shift matrix to curves 382, 384, 386 and 388 so as to calculate respective wave profile curves 462, 464, 466 and 468 of the respective cyan, magenta, yellow and black images. Note that the applied shift matrix was calculated based on the registration frames of left end 302, and is applied to the registration frames of right end 306.

As shown at step 3 of Fig. 2A above, processor 20 is configured to calculate for each color image respective pixel locations (e.g., locations 228), such that when one or more dummy pixels are implanted in locations 228, the increased width of the respective features at locations 228 compensates for the estimated geometric distortion of the respective color. In other words, the wave Y(X) and trapeze distortions are compensated by implanting the dummy pixels at the respective pixel locations. In an embodiment, the color of the dummy pixels and the size of the droplets may be defined based on a closest neighbor (e.g., one pixel left) to pixel location 228. As described above, the shift and the implant are calculated separately for each color. In some embodiments, each pixel has several levels that determine the size of the actual droplet, thus, the width of the printed feature. For example, controller 54 may feed into station 60 an input waveform of two bits that defines four levels for each pixel: no droplet (e.g., level zero), a single droplet forming a narrow pixel (e.g., level 1), two droplets forming a pixel having a medium width (e.g., level 2) and a wide pixel formed by three droplets (e.g., level 3). This embodiment is depicted in more details in Fig. 5 below.

In some embodiments, after applying the calculated shift matrix processor 20 identifies, based on the shape of each color image, which print bar 62 of a given color is jetting droplets that eventually print the largest bar width. In these embodiments, the image having the largest print bar width may serve as a reference for all other colors that will be corrected to align with the image of the given color. In other words, the implanted dummy pixels compensate for the bar to bar width delta, thus, compensating for the wave Y(X) and trapeze distortions as well as for other local distortions.

In other embodiments, processor 20 is configured to compensate for the distortion in the digital image (e.g., image 306) by removing pixels from the digital image instead of or in addition to implanting the dummy pixels in the respective digital image.

In other embodiments, processor 20 is configured to identify other distortions, such as bar to bar Y position delta as well as any local distortion. Processor 20 is configured to align all color images by implanting the dummy pixels at the calculated pixel locations. In the example of Fig. 4, all wave profile curves 462, 464, 466 and 468 are distorted. In an embodiment, dummy pixels are implanted at the respective calculated pixel locations of each color image.

For example, in the cyan image that is represented by curve 462, processor 20 is configured to calculate pixel locations that, when one or more dummy pixels are implanted therein, compensate for the geometric distortion of curve 462 relative to curve 360. The geometric distortions in the cyan image are represented by arrows 412, 422, 432 and 442, and are corrected by implanting the one or more dummy pixels at the respective pixel locations. Similarly, arrows 414, 424, 434 444 and 454 show the distortion in the magenta image represented by curve 464.

In some embodiments, the pixel locations are calculated for each of correction strips 372A-372D. As shown in Fig. 4, after applying the calculated shift matrix, the distortion at strips 372B and 372C are larger compared to the distortions at strips 372A and 372D, For example, arrows 422 and 424 of strip 372B are larger than arrows 412 and 414 of strip 372A. Thus, the density of implanted dummy pixels will be larger at strips 372B and 372C compared to the density of implanted dummy pixels at strips 372A and 372D.

In some embodiments, after implanting the dummy pixels, curves 462, 464, 466 and 468 are aligned with curve 360 and appear as a merged as a calculated left end 470. As described in Fig. 2A above, step 2 of Fig. 4 aligns all color images, thereby shaping all images as similar trapezes, and step 4 compensates for the trapeze distortion by implanting dummy pixels in all color images.

As described for frame 333 shown in Fig. 3 above, processor 20 is configured to produce two sets of wave profile curves (such as curves 362, 364, 366 and 368) and two shift matrices (such as curves 392, 394, 396 and 398) for sections 377 and 378, respectively. In some embodiments, processor 20 is configured to produce, based on the registration frames and registration marks of test columns 374 and 375, two sets of interpolated curves, such as interpolated curves 382, 384, 386 and 388 between the respective marks of each color. For the sake of conceptual clarity, the two sets of interpolated curves are referred to herein as first and second sets of interpolated curves, and the two shift matrices are referred to herein as first and second shift matrices, such that the first shift matrix corresponds to the first set of interpolated curves calculated for section 377, and the second shift matrix corresponds to the second set of interpolated curves calculated for section 378.

In some embodiments, processor 20 applies the first calculated shift matrix (such as curves 392, 394, 396 and 398) to the first set of interpolated curves (such as curves 382, 384, 386 and 388), so as to calculate respective first set of wave profile curves (such as profile curves 462, 464, 466 and 468) of the respective C, M, Y and K images of section 377. Similarly, processor 20 applies the second calculated shift matrix to the second set of interpolated curves, so as to calculate respective second set of wave profile curves of the respective C, M, Y and K images of section 378.

Note that the first shift matrix that was produced for correcting section 377, was calculated based on the registration frames of testing columns 373, and is applied to the registration frames of testing columns 375. Similarly, the second shift matrix that was produced for correcting section 378, was calculated based on the registration frames of testing columns 375, and is applied to the registration frames of testing columns 374.

In some embodiments, as described at step 3 of FIG. 2A above, processor 20 is configured to calculate for each color image of sections 377 and 378, two respective sets of pixel locations (e.g., locations 228 of FIG. 2A), referred to herein as first and second sets of pixel locations, respectively. In such embodiments, when one or more dummy pixels are implanted in the first and second sets of pixel locations, the increased width of the respective features at the first and second sets of pixel locations, compensates for the estimated geometric distortion of the color images of sections 377 and 378, respectively.

As described above for frame 300, the geometric distortions in the CMYK images are corrected by implanting the one or more dummy pixels at the respective pixel locations. In an example embodiment of frame 333, the first and second sets of geometric distortions are produced in the CMYK images of sections 377 and 378, respectively. The first and second sets of geometric distortions are corrected by implanting the one or more dummy pixels at the first and second pixel locations, respectively.

In some embodiments, by dividing image 376 to multiple sections, such as sections 377 and 378, processor 20 may improve the resolution of the geometric distortion estimation (as described in Fig. 3 above). In addition, processor 20 may improve the resolution of the correction by applying, for sections 377 and 378, respectively, the first and second shift matrices, and by implanting the one or more dummy pixels at the first and second pixel locations, respectively.

Fig. 5 is a schematic, pictorial illustration of a process sequence for implanting dummy pixels in a cyan digital image 500 to be printed in system 10, in accordance with an embodiment of the present invention. For the sake of clarity, the sequence described herein is carried out for a single color image, e.g., cyan, but in real-life printing, the estimated distortion and the pixel locations are calculated separately for each color image. Subsequently, the physical implantation of the dummy pixel is typically carried out simultaneously in all color images.

In some embodiments, the pixel locations can be similar for all colors images in case of a need to compensate for effects that are common to all color images.

The sequence begins at a step 1 with an original version of cyan digital image 500 (also referred to herein as a source image) having cyan pixels 502 arranged, for example, in an "O" shape at the center of image 500. As described in the process sequence of Fig. 2A above, station 55 acquires a digital image of a printout of original digital image 500 and, as shown in Fig. 3. Subsequently, processor 20 estimates the geometrical distortion and calculates the shift matrix required for each color. Image 500 may be a subset of any digital image, such as image 42 of Fig. 1 above.

At a step 2 (note that this is a different step 2 from the step 2 described in figure 2 above), processor 20 calculates the pixel locations that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion described above. In the example of Fig. 5, the pixel locations, such as locations 504, 506 and 514, are filled with an "XX" pattern. As described in Fig. 2A above, each dummy pixel is shifting the pixels located, at the same row, to the right of the respective pixel location. In the example of Fig. 5, the shift to the right is represented by the direction of an arrow 520 and a left direction is opposite to the direction of arrow 520. Thus, for a given pixel location, the pixels located at the same row, to the right of the given pixel location, are shifted by one pixel in the direction of arrow 520.

For example, a dummy pixel that will be implanted at location 506 will shift two cyan pixels 512 and two cyan pixels 510 of the same row, by one pixel location to the right. Similarly, a dummy pixel that will be implanted at location 514 will shift two cyan pixels 516 of the same row, by one pixel location to the right. Note that two cyan pixels 512 are located left of location 514, and therefore will not be affected by the implantation in location 514 and will remain in their original location shown in image 500 of step 1.

At a step 3 that corresponds to step 3 of Fig. 2A above, the dummy pixels are implanted at the respective pixel locations shown at step 2. In the example of Fig. 5, most of the calculated pixel locations are at the upper part of the cyan image, therefore, a frame 530 that represents the shape of the cyan image after the dummy pixel implantation has a trapeze shape.

As described above, the color of each implanted dummy pixel is determined by processor 20 and/or controller 54 based on any suitable algorithm. For example, the color and the width may be similar to the nearest neighbor pixel located, at the same row, one position to the left of the dummy pixel location. Therefore, in the example of cyan image 500, the pixels will have the droplet size value defined by the level of the waveform as described in Fig. 4 above. For example, the dummy pixels at locations 504 will have a cyan color, therefore, each pixel will receive a waveform having a level between 1 and 3 in accordance with the width of the nearest neighbor. The dummy pixels implanted at locations 506 and 514 do not have a cyan neighbor and therefore will have a waveform of level zero. The same calculation repeats for each color image.

Step 3 concludes the distortion correction of the cyan image and carried out in a similar manner for all other colors. As described at step 4 of Fig. 2A above, in order to compensate for the common trapeze shape of all color images, processor 20 calculates one or more shape-correcting locations, such that implanting one or more dummy pixels therein compensates for the trapeze shape of frame 530 and shapes the image of step 3 to a rectangular or parallelogram shape. In the example of Fig. 2A, calculated shape-correcting locations 230 are located mostly at the lower part of the trapeze-shaped image. The shape of image 500 at step 3 of Fig. 5 is similar to the shape of image 200 at step 3 of Fig. 2A above. Therefore, at a shape-correcting step (not shown) of image 500, the lower part will have more pixel locations than in the upper part.

Fig. 6 is a schematic, pictorial illustration of a method for setting pixel locations in a digital image 600 to be printed in system 10, in accordance with an embodiment of the present invention. Image 600 may replace, for example, image 500 of Fig. 5 above. In the example of Fig. 6, digital image 600 covers a portion of the printable width as supported by system 10.

In some embodiments, processor 20 is configured to set the pixel locations at predefined locations with respect to the estimated geometric distortion, implemented, for example, using a lookup table (LUT). In an example embodiment of Fig. 6, the predefined locations are calculated in percentage of valid width 612 set from a left end 614 (also referred to herein as a left edge) of the valid width. For example, a single location at strip 608 is set at 50% of valid width 612 as shown by an arrow 660. Processor 20 sets two pixel locations 610 and 630 at 25% and 50% of width 612, respectively, as shown by respective arrows 662 and 664. Similarly, at strip 604, pixel locations 610, 630 and 640 are set respectively at 25%, 50% and 75% of width 612, wherein pixel location 640 is shown by an arrow 666. Strip 602 comprises four pixel locations 610, 620 (represented by an arrow 668), 630 and 640, set respectively at 25%, 42%, 50% and 75% of valid width 612.

In some embodiments, setting the pixel location as percentage of the valid width allows applying the same pixel locating algorithm for any valid width caused by the width of the digital image, and thus, the difference between the respective digital image and sheet 50. In other embodiments, the calculated positions of the pixel locations and the method determining thereof may be carried out using any other suitable technique (e.g., not necessarily same locations for all colors).

Fig. 7 is a schematic, pictorial illustration of a method for setting pixel locations in a digital image 700 to be printed in system 10, in accordance with another embodiment of the present invention. Image 700 may replace, for example, image 500 of Fig. 5 above. In the example of Fig. 7, processor 20 sets non-printable areas 750, a valid width 730 of image 700 on sheet 50, and correction strips 702, 704, 706, and 708 having, respectively, four, three, two and one pixel locations.

In some embodiments, the position of the pixel locations may be constant at each strip but different between the strips, using a method referred to herein as a semi-random algorithm. For example, in strips 702 and 708 the respective positions of the pixel locations 712 and 724 are set in accordance with the LUT described in Fig. 6 above. In strip 704, pixel locations 716 are shifted relative to a vertical dashed line 714, which is aligned with location 712, by a predefined distance marked by an arrow 718. In an embodiment, the same shift is repeated in the position of all pixel locations 716 of strip 704.

In some embodiments, a different shift relative to line 714, is carried out in strip 706. In these embodiments, pixel locations 722 are shifted by another predefined distance illustrated by an arrow 720. In other embodiments, processor 20 may determine any other suitable direction of the predefined shift, for example, in a direction opposite to arrow 720.

The method described in Fig. 7 is not limited to the embodiments depicted above. In other embodiments, processor 20 is configured to apply any other suitable method for setting the position of each pixel location. For example, processor 20 is configured to set a shift distance that may vary along the respective strip. Additionally or alternatively, the strips having shifts may be selected systematically, e.g., alternately, or randomly.

Fig. 8 is a schematic, pictorial illustration of a method for aligning an implanted image 810 with sheet 50, in accordance with an embodiment of the present invention. In some embodiments, a frame 800 comprises respectively, left and right ends 802 and 804 of sheet 50, and implanted image 810, which may replace, for example image 500 of Fig. 5 above. As shown in frame 800, as a result of the implanted dummy pixels, image 810 has a width illustrated by a double-headed arrow 808, which is larger than the specified width in the original design of the digital image, and is also shifted to the right. Thus, image 810 is not centered relative to sheet 50, referred to above as image to substrate Y (Im2SubY), and may even cross over right end 804 of sheet 50 as shown in the example of frame 800.

Reference is now made to a frame 820. In some embodiments, processor 20 is configured to scale the size, e.g., width, of image 810 to the specified width of the original digital image, which is illustrated by a double-headed arrow 828. Processor 20 is further configured to center image 810 relative to sheet 50, by setting predefined non-printable areas having a specified width, illustrated by double-headed arrows 822.

In some embodiments, processor 20 (or any other processor coupled to or integrated with system 10) is configured set the width of image 810 by scaling the synthetic color image. The processor is further configured to center image 810 by shifting image 810 relative to sheet 50. Additionally or alternatively, the processor is configured to modify mechanically controlled parameters, e.g., moving the loading position of sheet 50 along the Y axis. Note that in some cases, it may be required, by design, to position the COG of the digital image at a predefined shift relative to the COG of sheet 50. In an embodiment, processor 20 is configured to set uneven non-printable areas between the edges of the digital image (e.g., image 810, or frame 820) and sheet 50.

In some embodiments, the methods described above may be applied, for example, in duplex printing systems in case of misalignment between images printed on different sides of the same sheet.

In some embodiments, system 10 may be defined as processor 20 and a printing subsystem, which represents all the other parts, modules and stations of system 10 but processor 20. In these embodiment, processor 20 is configured to estimate the geometric distortion and to calculate the pixel locations so as to correct the distortion by forming the subsequent digital image, and the printing subsystem is configured to print the subsequent digital image having the corrected geometric distortion.

Although the embodiments described herein mainly address correcting distortions in digital printing on sheets, the methods and systems described herein can also be used in other digital printing applications, such as in digital printing on a continuous web and/or a long print which contains a larger number of registration marks and/or registration frames.

It will thus be appreciated that the embodiments described above are cited by way of example, and that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and sub-combinations of the various features described hereinabove, as well as variations and modifications thereof which would occur to persons skilled in the art upon reading the foregoing description and which are not disclosed in the prior art. Documents incorporated by reference in the present patent application are to be considered an integral part of the application except that to the extent any terms are defined in these incorporated documents in a manner that conflicts with the definitions made explicitly or implicitly in the present specification, only the definitions in the present specification should be considered.

CLAIMS

1. A method for correcting distortion in image printing, the method comprising:

receiving a digital image acquired from a printed image;

estimating, based on the digital image, a geometric distortion in the printed image;

calculating one or more pixel locations that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion;

correcting the geometric distortion in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image; and

printing the subsequent digital image having the corrected geometric distortion.

2. The method according to claim 1, wherein implanting the one or more dummy pixels at a calculated pixel location comprises shifting one or more existing pixels at a given pixel location by an amount of the implanted one or more dummy pixels.

3. The method according to any of claims 1-2, wherein at least one of the pixel locations comprises a bar of pixels along a section of a column or row of the digital image, and wherein correcting the geometrical distortion comprises implanting the dummy pixels in the bar.

4. The method according to claim 3, wherein at least another of the pixel locations comprises an additional bar of pixels located along an additional section of the row or column, and wherein correcting the geometrical distortion comprises implanting the dummy pixels in the additional bar.

5. The method according to claim 4, wherein implanting the dummy pixels comprises shifting the additional section relative to the section.

6. The method according to any of claims 1-2, wherein the digital image comprises at least first and second colors, and wherein correcting the geometric distortion comprises correcting a difference between printed first and second widths of the first and second colors, respectively.

7. The method according to any of claims 1-2, wherein correcting the geometric distortion comprises compensating for a trapeze shape of a print of the digital image.

8. The method according to any of claims 1-2, wherein estimating the geometric distortion comprises comparing at least part of the printed image with a reference image.

9. The method according to any of claims 1-2, and comprising, based on the digital image, qualifying or disqualifying at least one of the printed image and a print of the subsequent digital image.

10. The method according to any of claims 1-2, and comprising, based on the digital image, estimating at least an additional geometric distortion of the printed image relative to a source image used for printing the printed image.

11. The method according to claim 10, wherein the additional geometric distortion comprises a tilt of the printed image relative to the source image, and comprising correcting the tilt by applying, to the source image, a pre-compensation for the tilt.

12. The method according to claim 10, wherein the additional geometric distortion comprises a color to color position difference between first and second colors of the printed image, and comprising correcting the color to color position difference by shifting, in the subsequent digital image, at least one of the first and second colors.

13. The method according to any of claims 1-2, wherein the digital image comprises at least first and second color images, and comprising aligning an edge of the first and second color images to one another by shifting the edge of the second color image to align with the edge of the first color image.

14. The method according to any of claims 1-2, wherein the digital image comprises multiple color images, wherein implanting the one or more dummy pixels comprises, for a given dummy pixel at a given pixel location in a given color image, setting a waveform that determines a size of the given dummy pixel based on one or more selected pixels adjacent to the given pixel location, and wherein printing the subsequent digital image comprises printing the given dummy pixel in accordance with the waveform.

15. The method according to any of claims 1-2, wherein the digital image comprises multiple registration marks, and wherein estimating the geometric distortion comprises analyzing the geometric distortion between the registration marks.

16. The method according to claim 15, wherein the digital image comprises registration marks in at least one of: (i) a margin of the digital image and (ii) an interior of the digital image.

17. The method according to claim 15, wherein at least two of the registration marks comprise a bar of the registration marks arranged along a section of a column of the digital image.

18. An apparatus for correcting distortion in image printing, the apparatus comprising:

an interface, which is configured to receive a digital image acquired from a printed image; and

a processor, which is configured to:

estimate, based on the digital image, a geometric distortion in the printed image;

calculate one or more pixel locations that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion; and

correct the geometric distortion in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image.

19. The apparatus according to claim 18, wherein the processor is configured to shift one or more existing pixels at a given pixel location by an amount of the implanted one or more dummy pixels.

20. The apparatus according to any of claims 18-19, wherein at least one of the pixel locations comprises a bar of pixels along a section of a column or row of the digital image, and wherein the processor is configured to correct the geometrical distortion by implanting the dummy pixels in the bar.

21. The apparatus according to claim 20, wherein at least another of the pixel locations comprises an additional bar of pixels located along an additional section of the row or column, and wherein the processor is configured to correct the geometrical distortion by implanting the dummy pixels in the additional bar.

22. The apparatus according to claim 21, wherein the processor is configured to shift the additional section relative to the section by implanting the dummy pixels.

23. The apparatus according to any of claims 18-19, wherein the digital image comprises at least first and second colors, and wherein the processor is configured to correct the geometrical distortion by correcting a difference between printed first and second widths of the first and second colors, respectively.

24. The apparatus according to any of claims 18-19, wherein the processor is configured to correct the geometrical distortion by compensating for a trapeze shape of a print of the digital image.

25. The apparatus according to any of claims 18-19, wherein the processor is configured to estimate the geometric distortion by comparing at least part of the printed image with a reference image.

26. The apparatus according to any of claims 18-19, wherein, based on the digital image, the processor is configured to qualify or to disqualify at least one of the printed image and a print of the subsequent digital image.

27. The apparatus according to any of claims 18-19, wherein the processor is configured to estimate, based on the digital image, at least an additional geometric distortion of the printed image relative to a source image used for printing the printed image.

28. The apparatus according to claim 27, wherein the additional geometric distortion comprises a tilt of the printed image relative to the source image, and wherein the processor is configured to correct the tilt by applying, to the source image, a pre-compensation for the tilt.

29. The apparatus according to claim 27, wherein the additional geometric distortion comprises a color to color position difference between first and second colors of the printed image, and wherein the processor is configured to correct the color to color position difference by shifting, in the subsequent digital image, at least one of the first and second colors.

30. The apparatus according to any of claims 18-19, wherein the digital image comprises multiple registration marks, and wherein the processor is configured to estimate the geometric distortion by analyzing the geometric distortion between the registration marks.

31. The apparatus according to claim 30, wherein the digital image comprises registration marks in at least one of: (i) a margin of the digital image and (ii) an interior of the digital image.

32. The apparatus according to claim 30, wherein at least two of the registration marks comprise a bar of the registration marks arranged along a section of a column of the digital image.

33. A system, comprising:

a processor, which is configured to:

receive a digital image acquired from a printed image;

estimate, based on the digital image, a geometric distortion in the printed image;

calculate one or more pixel locations that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion; and correct the geometric distortion in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image; and

a printing subsystem, which is configured to print the subsequent digital image having the corrected geometric distortion.

34. The apparatus according to claim 33, wherein the digital image comprises at least first and second color images, and wherein the processor is configured to align an edge of the first and second color images to one another by shifting the edge of the second color image to align with the edge of the first color image.

35. The apparatus according to claim 33, wherein the digital image comprises multiple color images, wherein for a given dummy pixel at a given pixel location in a given color image, the processor is configured to set a waveform that determines a size of the given dummy pixel based on one or more selected pixels adjacent to the given pixel location, and wherein the printing subsystem is configured to print the given dummy pixel in accordance with the waveform.

36. The apparatus according to claim 33, wherein the digital image comprises multiple registration marks, and wherein the processor is configured to estimate the geometric distortion by analyzing the geometric distortion between the registration marks.

37. The apparatus according to claim 36, wherein the digital image comprises registration marks in at least one of: (i) a margin of the digital image and (ii) an interior of the digital image.

38. The apparatus according to claim 36, wherein at least two of the registration marks comprise a bar of the registration marks arranged along a section of a column of the digital image.

39. A computer software product, the product comprising a tangible non-transitory computer-readable medium, in which program instructions are stored, which instructions, when read by a processor, cause the processor to:

receive a digital image acquired from a printed image;

estimate, based on the digital image, a geometric distortion in the printed image;

calculate one or more pixel locations that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion; and

correct the geometric distortion in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image.

40. A printing system, comprising:

a printing subsystem comprising an intermediate transfer member (ITM) configured to receive ink droplets from an image forming station to form an ink image thereon, and to form a printed image by transferring the ink image to a target substrate; and

a processor, which is configured to:

receive a digital image acquired from the printed image;

estimate, based on the digital image, a geometric distortion in the printed image;

calculate one or more pixel locations that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion; and

correct the geometric distortion in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image,

wherein the printing subsystem is configured to print the subsequent digital image having the corrected geometric distortion.

41. A method for correcting distortion in image printing, the method comprising:

printing a printed image by applying, to an intermediate transfer member (ITM), ink droplets from an image forming station to form an ink image thereon, and transferring the ink image from the ITM to a target substrate;

receiving a digital image acquired from the printed image;

estimating, based on the digital image, a geometric distortion in the printed image;

calculating one or more pixel locations that, when one or more dummy pixels are implanted therein, compensate for the estimated geometric distortion;

correcting the geometric distortion in a subsequent digital image to be printed, by implanting the one or more dummy pixels at the one or more calculated pixel locations in the subsequent digital image; and

printing the subsequent digital image having the corrected geometric distortion.

42. A method for correcting distortion in image printing, the method comprising:

receiving a digital image acquired from a printed image;

estimating, based on the digital image, a geometric distortion in the printed image;

calculating one or more pixel locations that, when one or more given pixels are removed from the digital image, compensate for the estimated geometric distortion;

correcting the geometric distortion in a subsequent digital image to be printed, by removing the one or more given pixels at the one or more calculated pixel locations in the subsequent digital image; and printing the subsequent digital image having the corrected geometric distortion.

43. A system, comprising:

a processor, which is configured to:

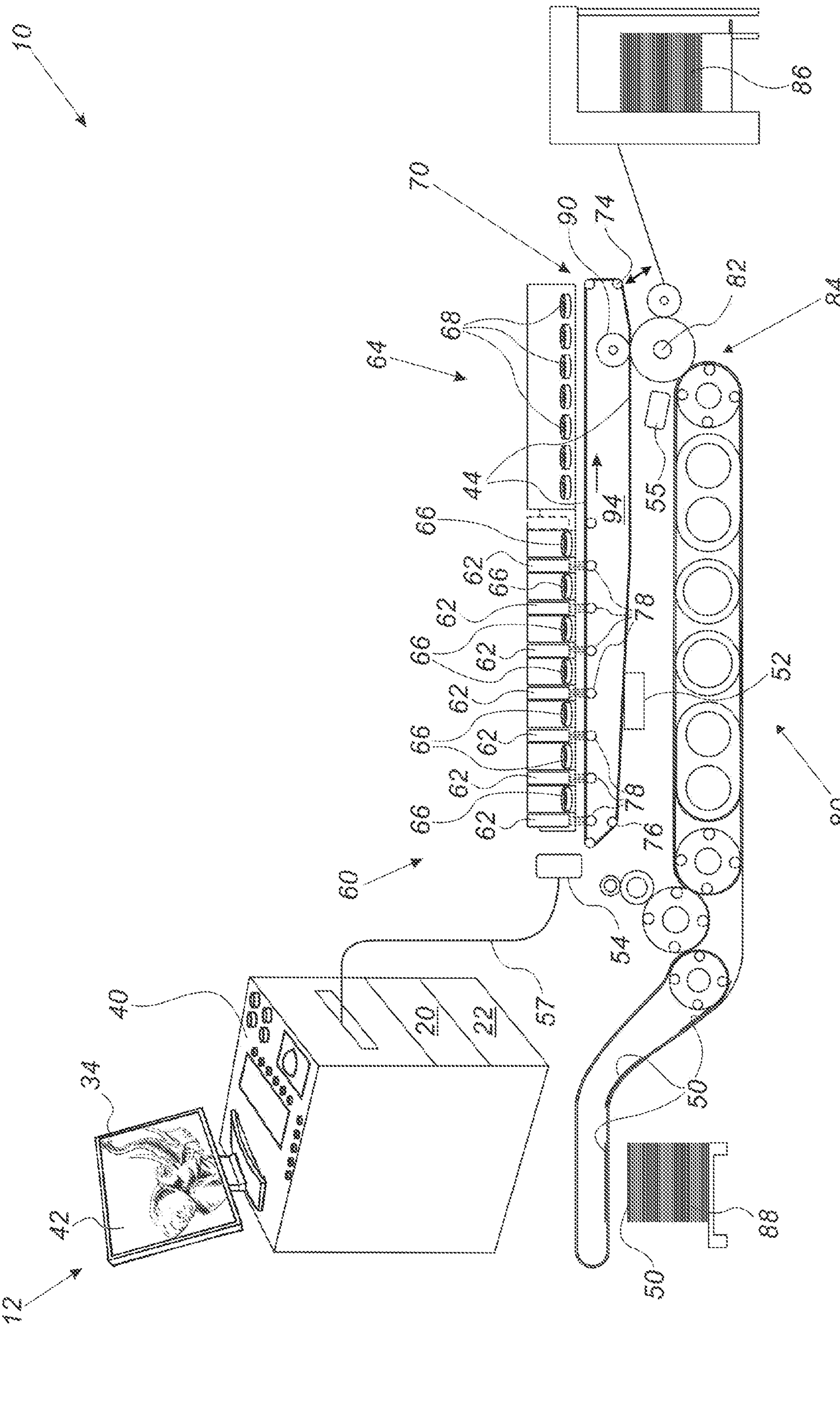
receive a digital image acquired from a printed image;

estimate, based on the digital image, a geometric distortion in the printed image;

calculate one or more pixel locations that, when one or more given pixels are removed from the digital image, compensate for the estimated geometric distortion; and

correct the geometric distortion in a subsequent digital image to be printed, by removing the one or more given pixels at the one or more calculated pixel locations in the subsequent digital image; and

a printing subsystem, which is configured to print the subsequent digital image having the corrected geometric distortion.


10
12
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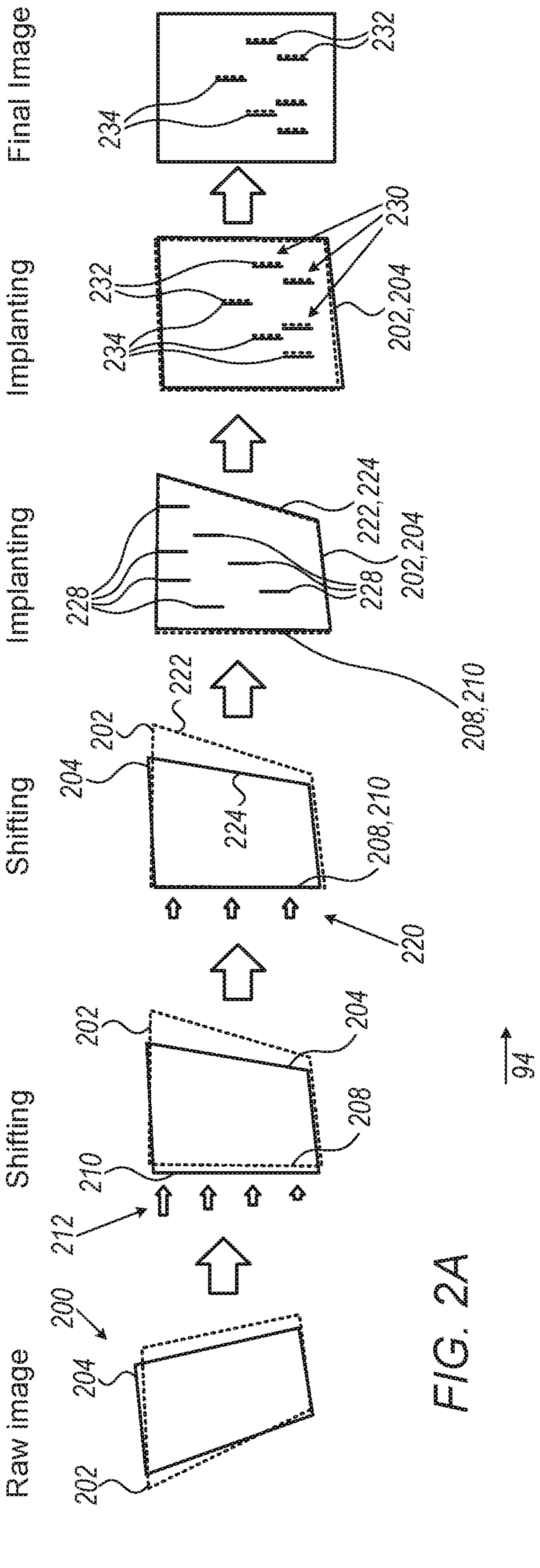
86
88
90
94

FIG. 1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STEP 1
Shifting
STEP 2
Shifting
STEP 3
Implanting
STEP 4
Implanting
STEP 5
Final Image
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202
204
208
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212
220
222
224
202,204
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222,224
228
230
232
234
94

FIG. 2A

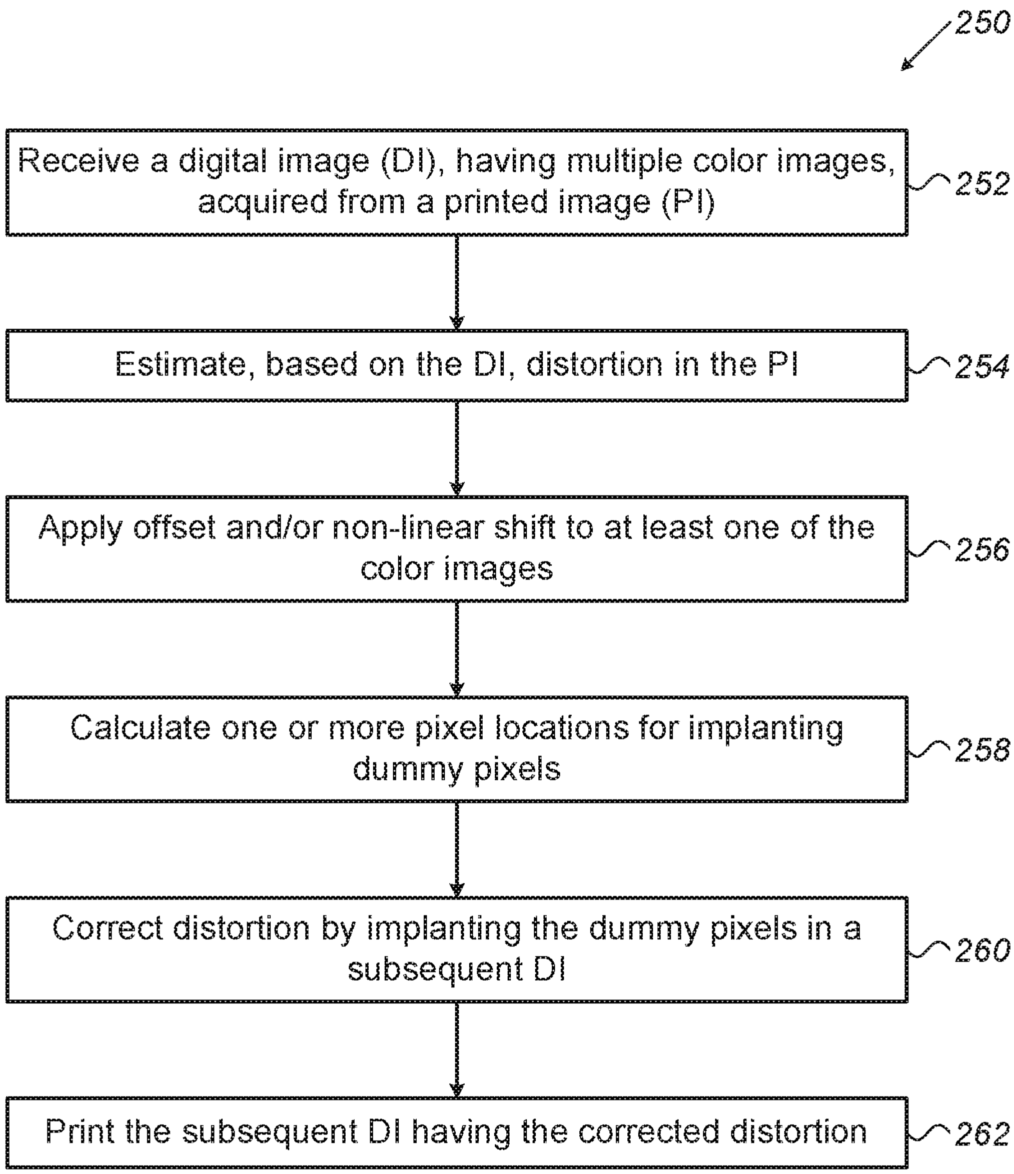

250
Receive a digital image (DI), having multiple color images, acquired from a printed image (PI)
252
Estimate, based on the DI, distortion in the PI
254
Apply offset and/or non-linear shift to at least one of the color images
256
Calculate one or more pixel locations for implanting dummy pixels
258
Correct distortion by implanting the dummy pixels in a subsequent DI
260
Print the subsequent DI having the corrected distortion
262

FIG. 2B

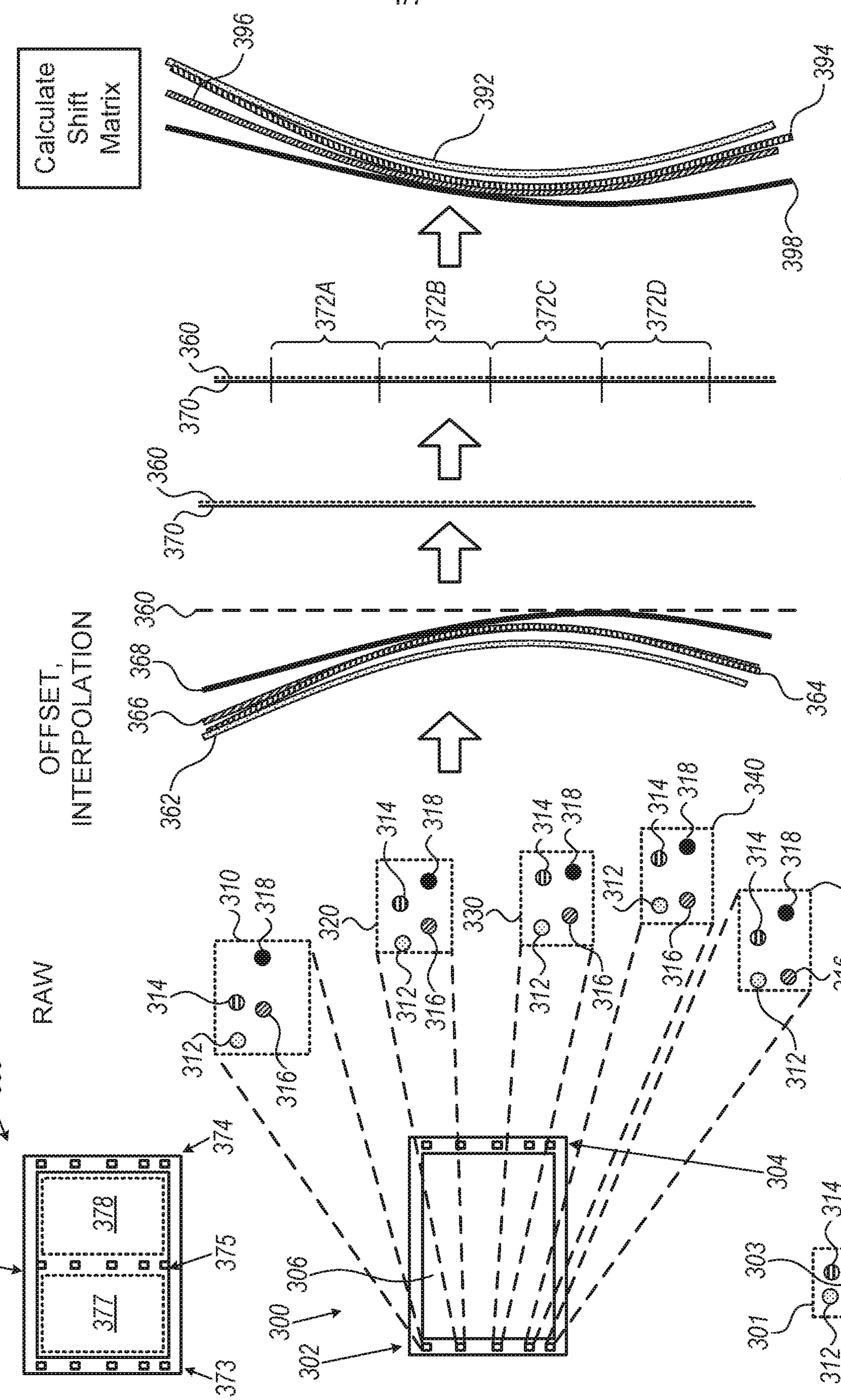
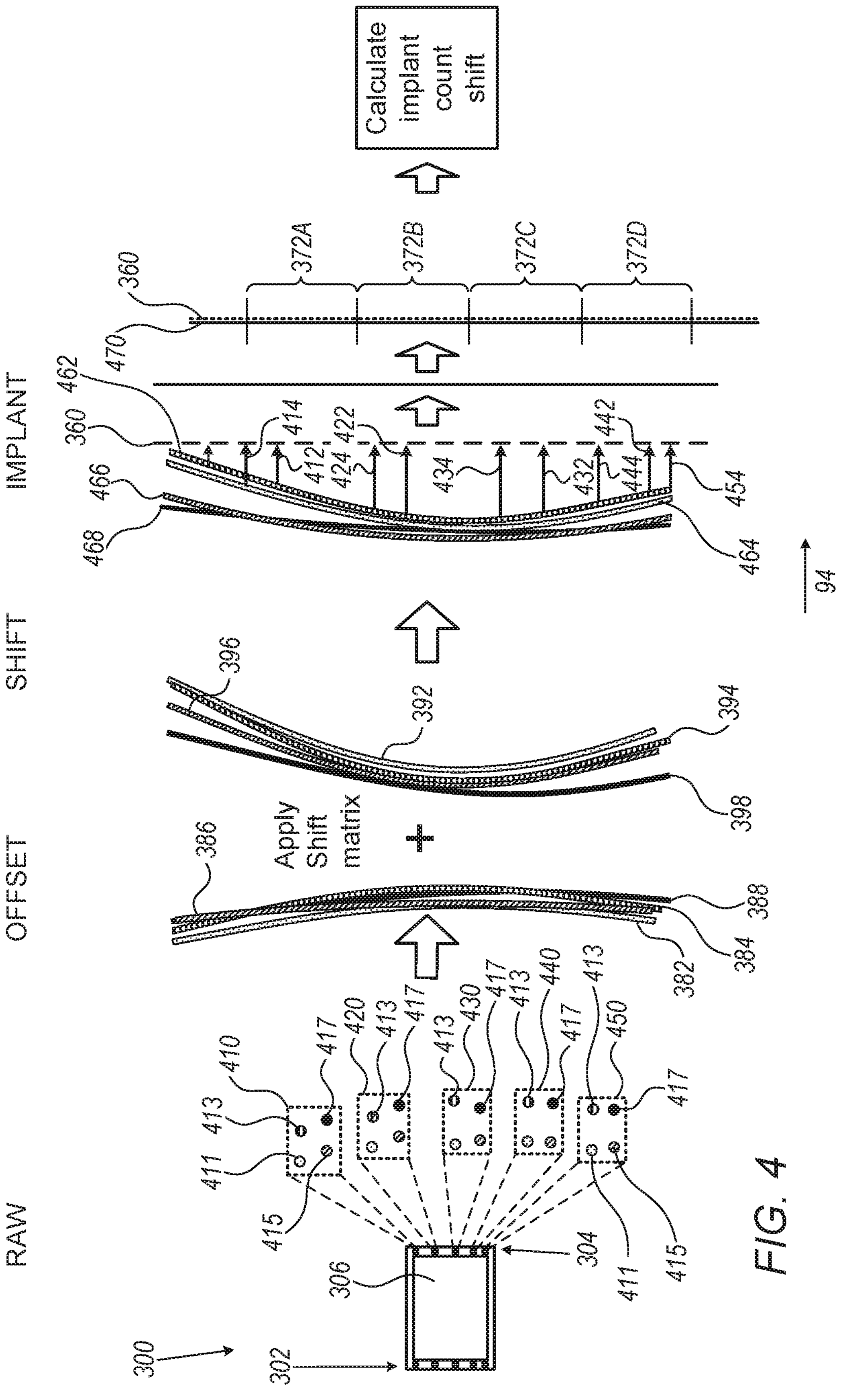


FIG. 3


RAW
OFFSET
SHIFT
IMPLANT
Apply Shift matrix
+
Calculate implant count shift
300
302
304
306
410
411
413
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450
382
384
386
388
392
394
396
398
360
412
414
422
424
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454
462
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466
468
470
372A
372B
372C
372D
94

FIG. 4

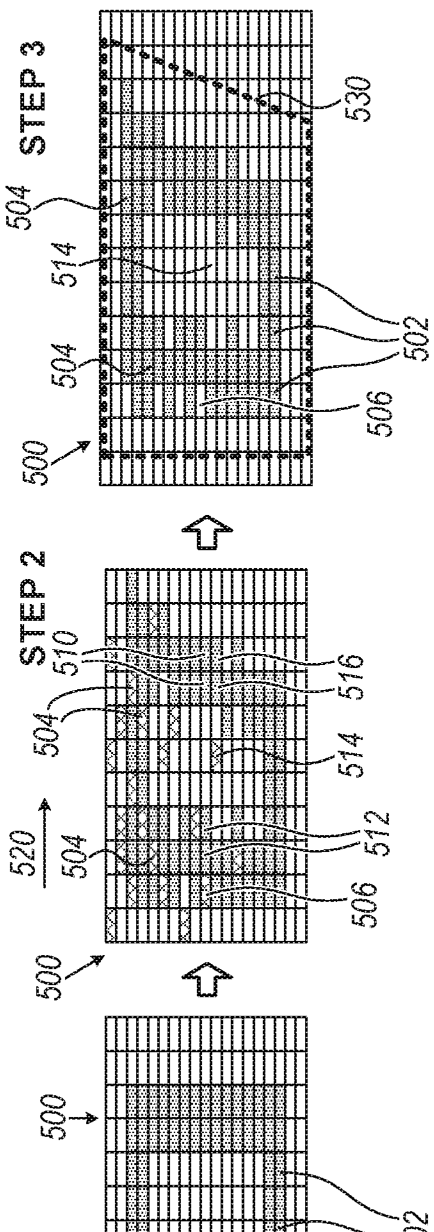
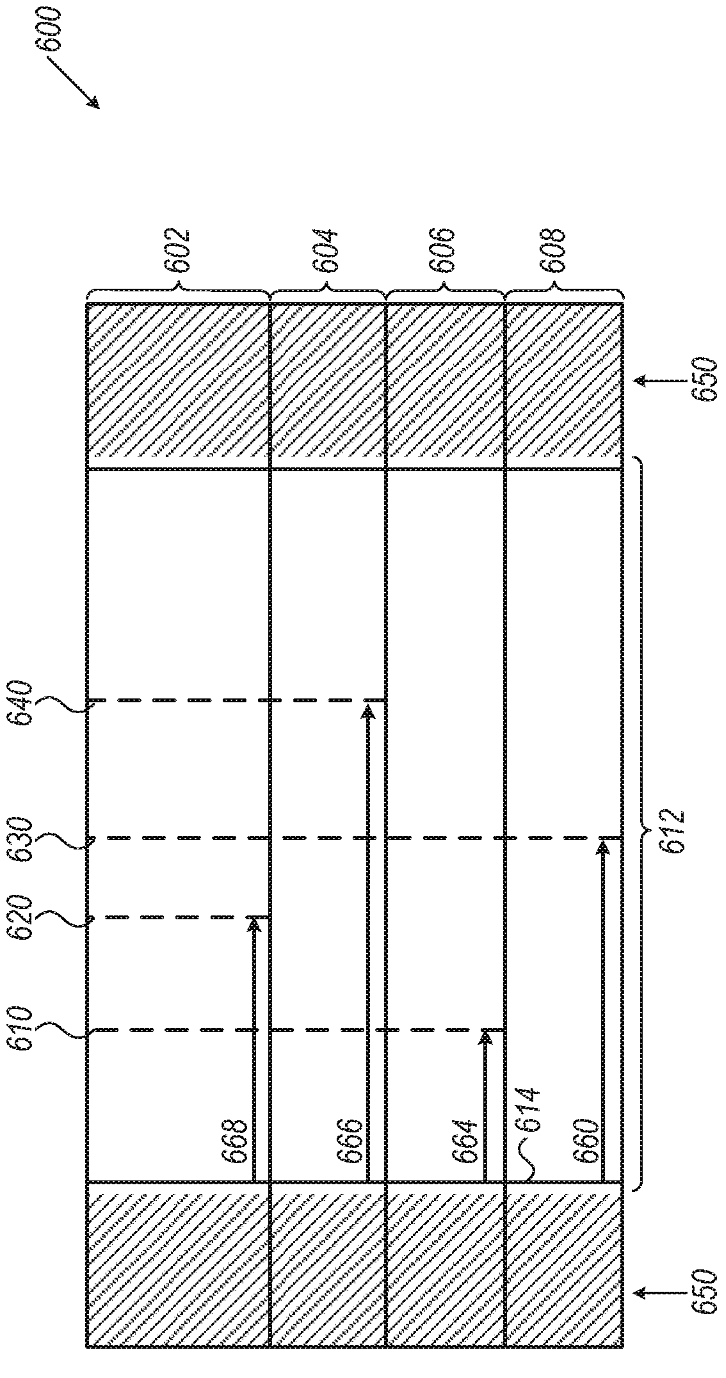

STEP 1
STEP 2
STEP 3
500
502
504
506
510
512
514
516
520
530

FIG. 5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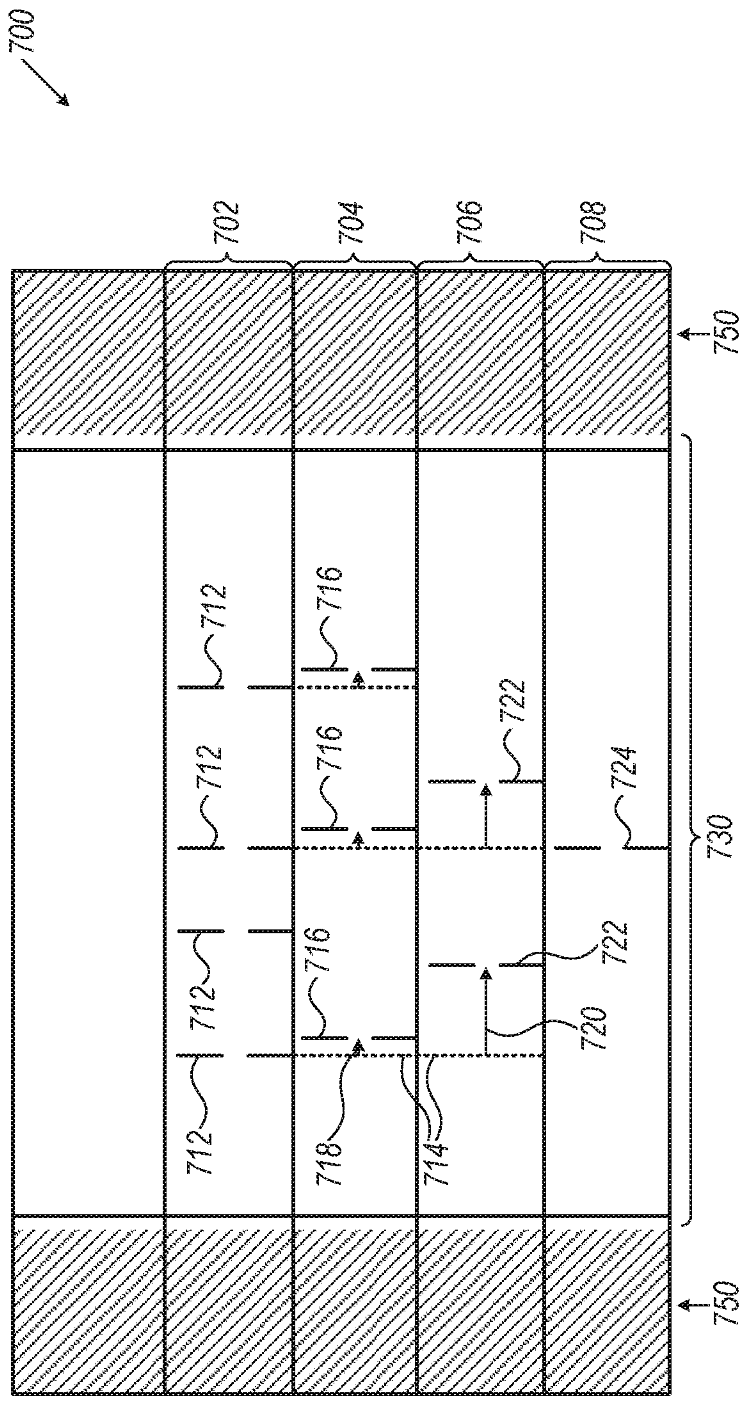
602
604
606
608
610
612
614
620
630
640
650
660
664
666
668

FIG. 6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702
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706
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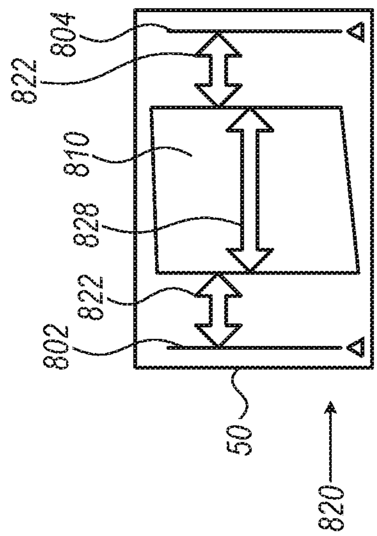
750
712
716
722
724
730
720
718
714
750

FIG. 7


804
822
810
828
822
802
50
820

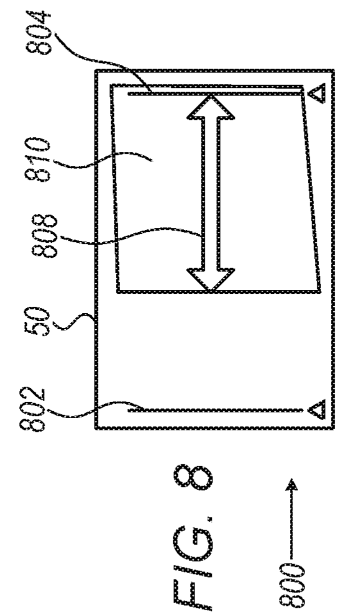

804
810
808
50
802
800

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2019/056746

A. CLASSIFICATION OF SUBJECT MATTER
IPC (20190101) B41J 2/21, G06K 15/02
CPC (20130101) B41J 2/2135, B41P 2233/00, G06K 15/1867
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (20190101) B41J 2/21, G06K 15/02
CPC (20130101) B41J 2/2135, B41P 2233/00, G06K 15/1867

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Databases consulted: Orbit
Search terms used: correction subsequent image compare ink inspection

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004200369 A1 Brady 14 Oct 2004 (2004/10/14) ¶¶10,47,53,66-68,	1-43
A	US 2015174925 A1 CASIO COMPUTER 25 Jun 2015 (2015/06/25) abstract, ¶41	1-43
A	JP 2016185688 A HITACHI INDUSTRY EQUIPMENT SYSTEMS 27 Oct 2016 (2016/10/27) abstract	1-43

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 Nov 2019	28 Nov 2019

Name and mailing address of the ISA:	Authorized officer
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2019/056746

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