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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
19 February 2004 (19.02.2004)

PCT

(10) International Publication Number
WO 2004/015980 A2

(51) International Patent Classification[7]: H04N

(21) International Application Number: PCT/US2003/025111

(22) International Filing Date: 11 August 2003 (11.08.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/402,233 12 August 2002 (12.08.2002) US

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(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)*
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— *of inventorship (Rule 4.17(iv)) for US only*

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 2004/015980 A2

(54) Title: SYSTEM AND ITS APPARATUSES FOR IMAGE REPRODUCTION AND RECORDING WITH THE METHODS FOR POSITIONING, PROCESSING AND CONTROLLING

(57) Abstract: Image reproduction and recording system, having exclusive plurality of uses, with the methods for positioning, processing and controlling, with flexible operations (hand, robot, vehicle) of head carrier, works based on mechanical-guiding-apparatus-free positioning system. The common apparatuses include: head Gamier, sprayer/reader or sprayer/reader array, and computer. Additional apparatuses used in relative-motion-based method or wave-based method, include operation-module(OM) and motion-detectors(MD), or operation-unit(OU) and communication-units(CU's), respectively. The MD and OM provide the information of positioning for computer to determines the relative position and direction of the head array on head carrier. The CU's radiate and receive signal needed for determining distance information. The OU processes and converts the received signal into distance-related data and pass to computer. The computer determines the coordinates of a head in the head array from these data, and sends it back to OU or OM. Then the OU or OM sends the color data and spraying commands to head array, and provides power for head, or sends reading commands to reader array for reading color data.

System and its apparatuses for image reproduction and recording with the methods for positioning, processing and controlling

CROSS-REFERENCE TO RELATED APPLICATION

The application claims the priority from provisional U.S. Patent Application No. 60/402,233, filed on August 12, 2002 entitled "System and its apparatuses for image reproduction and recording with the methods for positioning, processing and controlling".

FIELD OF THE INVENTION

The present invention relates to an image reproduction and recording system with a flexible operation (hand, robot, vehicle) of head carrier, and the corresponding apparatuses and methods for positioning, processing, and controlling. The motivation is to build a flexible operation (i.e. without precise mechanical-apparatus for positioning) for image reproduction and recording system, instead of present conventional image reproduction and recording systems in plurality of uses. The conventional mechanical-apparatus based systems are complex, costly, and not flexible, especially for very large printing area. Due to the flexibility of this invention in operation, the size of image that will be reproduced or will be recorded can be as large as the wall of a building and golf course, or can be as small as any size as long as it still makes sense. Therefore, it can be used for plurality of applications, such as images and patterns on building wall or cliff, golf courses, basketball courts, football/soccer fields, billboards, posters, portraits and paintings, industry design blue prints, industry decorations, decoration arts (such as depositing a pattern on china arts), home painting and wall decorations, archaeological image/pattern taking and museum image/pattern backup, sculptures, etc. It can be used for applications either on any flat surface, or on any curved surface. The invention includes the constitutions and designs of the system and its apparatus, including the motion detectors, operation modules, communication units, head carrier, operation unit, sprayer / sprayer-array and image reader /reader-array. The invention also relates to the concepts, ideas, theories, and methods for positioning, processing, and controlling of the image reproduction and recording system, and relates to hardware signal processing and software data processing.

BACKGROUND OF THE INVENTION

The conventional image reproduction and image recording systems, such as the printing devices and scanning devices sold in the electronics store and those described in US patents 5968271, 5273059, 5203923, 4839666, 5707689, 6369906, 5642948, 5272543 [1-8] etc are based on the track-guided positioning systems. The spraying head or reading (recording) head is driven by electric motors and is limited on two tracks in two directions through the precise mechanical-apparatus for positioning. Therefore, they have limitation in size and service objectives, and they have no flexibility for plurality of applications, such as image on hardboards, on the walls, with huge size or on a curved surface, etc. Also the conventional system is mechanical-apparatus based and so is complex and costly. So the motivation of this invention is to build the flexible hand-operated, or robot-operated or vehicle carried systems for image reproduction and recording, instead of present conventional image reproduction and recording systems. Due to the flexibility of operation, the image that will be reproduced or will be recorded can be as large as the wall of a high building, or can be as small as any size as long as it still makes sense. Therefore, it can be used for plurality of applications mentioned above. It can be used for either any flat surface, or any curved surface. The invention includes the constitutions and designs of the system and its apparatus: motion detectors, communication units, head carrier, operation unit, operation modules, sprayer / sprayer-array and image reader /reader-array.

SUMMARY OF THE INVENTION

The key spirits of present invention is the image reproduction and recording system with a flexible hand-operated or robot-operated or vehicle carried head carrier, and the corresponding apparatuses and methods for positioning, processing, and controlling. The system is flexible, (hand-operational, or robot-operational or vehicle carried), easy and very convenient to use for a plurality of users from industries, offices and home, home decorations, entertainment and arts, etc., instead of the complex and costly precise mechanical-apparatus based systems in present conventional image reproduction systems.

A further object of the present invention is to provide system constitutions and apparatuses for head positioning, data processing, and head controlling.

To achieve the above objects, in the first aspect of the invention, the image reproduction (sub)system reproduces the image on any surface based on image data stored in computer, by causally moving the flexible-operation (hand, robot, vehicle) apparatus, i.e. head carrier, on the surface. The methods for image reproduction systems are classified into two catalogs: the wave-based method and relative-motion-based method. Both systems comprise these apparatuses: head carrier, sprayer / sprayer array, and a computer. Besides these apparatuses, the relative-motion-based method includes two relative motion detectors (MD) and an operation module (OM). The wave-based method includes the communication units (CU) and an operation unit (OU).

In the relative-motion-based method, the *system operation procedures* include: OM executes the commands from computer to read the motion information of head from MD, and organizes this information as time-sequences. Then OM sends these time-sequences to computer by multi paths (in parallel). Computer processes the information for locator positioning and determining the coordinates of the head in the head array. The OM executes the commander from computer to control the action (spraying or reading) of the head in head array. For recording system, the OM takes the image information at each image pixel on sensor array, and organizes this information as time-sequences and sends them to computer. Also, as the alternates, any computer-mouse techniques can be employed as MD.

In the wave-based method, the *system operation procedures* include: operation unit (OU) produces and sends the signal current to the transmitting CU. The transmitting CU radiates and the receiving CU receives the radio frequency (RF), electromagnetic wave, light or ultrasonic signals that carry the information of the phase differences or the time differences. The information is sent back to the OU from the receiving CU. The OU processes and converts the information into the data of phase differences or time differences, and sends the data to computer. Another alternate uses Doppler effect to detect the velocity of the receiving CU, and computer calculates the moving distance by integrating the velocity.

Computer processes these data and inverses the position coordinates of the sprayer/sprayer array by using the claimed positioning methods in this invention. According to the position coordinates, computer searches for the nearest pixel to this position in the image data file stored in disk of the computer and takes the color data of this pixel, and sends the data to OU or OM. Then OU or OM sends commands and power to the spray head to execute the jobs. Computer then records the history of the image-reproducing process. Any pixel on the computer screen, of which the corresponding image has been reproduced on the image surface, will be marked by the computer and will not be reproduced again if the sprayer moves back to the same position later.

The CU in the wave-based system or MD in relative-motioned-based system is also called head locator. Usually there are two of them. With the first one, the second CU or MD is used for determining the sprayer array direction, so that the position of each sprayer/reader in the sprayer/reader array is determined.

In the second aspect of the invention, the image recording (sub)system takes the image digital data from any image surface to computer for storing and reproducing, and also by causally moving the hand-operation or robot-operation or vehicle carried apparatus, on the surface. All apparatuses and procedures in the systems are same as that in the image reproduction systems, but use image reader/reader array instead of sprayer/sprayer array. Trigged by a trigger clock, the coordinate information and color data are taken from the image surface at the triggered moment and are sent back to the computer. The computer processes the information and data promptly or stores them into a file for processing lately. The computer inverses the coordinate information into coordinates. The coordinates at the triggered moment may not be just at a pixel on the pre-formatted pixel grids. So then the computer calculates the color values at all pixels on the pre-formatted pixel grids based on the obtained coordinates and color data, by using interpolation method.

In the third aspect of the invention, the apparatuses, i.e. motion detectors (called head locators) and operation module (OM), determine the relative position and direction of head array for the relative-motion-based system.

In the fourth aspect of the invention, the apparatuses, i.e. communication units (CU), send and receive the signal needed for determining the distance between transmitting CU and receiving CU for the wave-based system. The CU's installed on head carrier are called head locators.

In the fifth aspect of the invention, the apparatuses, i.e. operation unit (OU) process the signals from CU, convert the signal into distance-related data and provide the data to computer, and send the color data and action commands to the head, and also provides power supply for the head. In the sixth aspect of the invention, the apparatus, such as the head carrier or a hand hold brush like body, provides a flexible operation to move the head with a guaranteed constant fly-height.

In the seventh aspect of the invention, the computer software det...mines the position of head or heads in head array according to the information from OU or OM, and sends back to OU or OM the commands and color data of the pixels corresponding to this position.

The final aspect of the invention provides the theories, concepts, ideas, and methods corresponding to each structure, embodiment, apparatus, and procedure, for positioning, processing and controlling the image reproduction and recording, including hardware signal processing and software data processing.

BRIEF DESCRIPTION OF THE DRAWINGS

A better understanding of the invention will be obtained by reading the detail description of the invention below, with reference to the following drawings, in which:

FIG. 1 is a view showing the constitution of one of the preferred embodiments for the image reproduction and recording system according to the invention, with the CU (communication unit) on the corners, and the color material tanks on the head carrier or in the cartridge that are build together with the head.

FIG. 2 is a view showing the constitution of other preferred embodiments for the system according to the invention: (a) the color material tanks on the ground, (b) three CU on the corners, (c) four CU on the middle edges, (d) two CU on the bottom corners.

FIG. 3 is the schematic chart of one of the preferred embodiments for the head carrier with single head according to the invention.

FIG. 4 is the schematic chart of one of the preferred embodiments for the head carrier with head array according to the invention.

FIG. 5 is the schematic chart of one of the preferred embodiments for the head carrier with sprayer array on ink-jet cartridge according to the invention.

FIG. 6 is the schematic chart of the preferred embodiments for the transmitting CU's: (a) Radio frequency (RF) antenna, (b) single-light-source transmitter, (c) four-light-source transmitter, (d) ultrasonic transmitter.

FIG. 7 is the schematic chart of the preferred embodiments for receiving CU's: (a) RF antenna, (b) single-photo-detector receiver, (c) two-photo-detector receiver, (d) four-photo-detector receiver, (e) corner single-photo-detector, (f) corner single-photo-detector with curved substrate, (g) ultrasonic receiver.

FIG. 8 is the schematic chart of one of the preferred embodiments for relation motion detector (MD).

FIG. 9 is a schematic block diagram of the control and processing for one of the preferred RF-based systems according to the invention.

FIG. 10 is a schematic block diagram of the control and processing of another of the preferred RF-based system according to the invention.

FIG. 11 is a schematic block diagram of phase processing for the RF-based systems.

FIG. 12 is a schematic block diagram of the control and processing of one of the preferred modulation-based systems according to the invention, with FOUR wavelengths/frequencies.

FIG. 13 is a schematic block diagram of the control and processing of another of the preferred modulation-based systems, with TWO wavelengths/frequencies.

FIG. 14 is a schematic block diagram of the control and processing of another of the preferred modulation-based systems, with four wavelengths/frequencies.

FIG. 15 is a schematic block diagram of the control and processing of another of the preferred modulation-based systems, with two wavelengths/frequencies.

FIG. 16 is a schematic block diagram of the control and processing of one of the preferred time-based systems with an ultrasonic approach.

FIG. 17 is a schematic block diagram of the control and processing of one of the preferred time-based systems with another ultrasonic approach.

FIG. 18 is a schematic chart of the contour curves for constant phase differences (hyperbola), and constant phase sum (ellipse).

FIG. 19 is a flow chart of the position data processing and control for a single head.

FIG. 20 is a flow chart of the position data processing and control for the head array.

FIG. 21 is a schematic chart of the wrapping of current-phase-relation of in a digital phase detector (DPD) and the wrapped region in the 2-D phase space.

FIG. 22 is a schematic chart of data correlation processing for relative-motion-based system: image correlation conception and simple motion.

FIG. 23 is a schematic chart of data correlation processing for relative-motion-based system: complex motion.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is to provide the image reproduction and recording systems with the flexibility, easiness, and convenience to use for a plurality of users from industries, offices and homes, and home decorations. The systems are flexible and consist of an easy hand-operation or robot-operation or vehicle carried apparatus, instead of the complex and costly mechanical apparatus-based systems in present conventional image reproduction and recording systems in plurality of uses.

< DICTIONARY >

For convenient in reading this invention, building a 'dictionary' for definitions of some terms is necessary. In this invention,

(1) In "Flexible operations": "hand-operation" means operation by hand of a human being; both "robot-operation" (such as the 'spiderman'-like) and "vehicle carried operation" means the powered-apparatus-aided operation, but without precise mechanical-apparatus (such as track guide for guiding the printing head or scanning head in the conventional printer, or scanner) for positioning, if the operation needs a power that exceeds the power of the human being, or if the environment of operation is not accessible for human being;

(2) The term "image generation" means reproducing (printing, painting, spraying, and deposition) or recording (scanning, and reading) image or pattern on or/and from any surface.

(3) The term "image" in phases "image reproduction or image recording" has dual meanings: (a) any predetermined pattern or deposition to be reproduced, or any pattern or deposition to be recorded, which has already existed and was resulted from human's arts or natural's arts; (b) the image stored in computer, which could be recorded by scanner, or taken by digital camera, digital camcorder, etc.

(4) The term "head" in this invention means either sprayer for image reproduction or reader for image recording. Some time the "head" also means the part on which the head is installed;

(5) The term "sprayer" in this invention means the ink-jet, paint sprayer, or any other devices for material deposition. "Spray" or "spraying" means any action for material deposition;

(6) The term "reader" in this invention means any device that takes the image information from a predetermined pattern or deposition, such as the image sensor in an image scanner or in a camera. "read" or "reading" means any action of the reader;

(7) The "element" of an array is a general term referring to an element in one-dimensional array in positioning method description and claims. However, in image reproduction or recording system, it refers to a head in head array.

(8) The CU or MD built on head carrier is called head "locator" in claims "image reproduction and recording system"

(9) However "positioning locator" in the claims of positioning methods is a general term and is not necessary only for "image reproduction or recording system";

(10) "Light" or "photo" means visible or invisible, coherent or non-coherent electromagnetic radiation from T-ray to X-ray;

(11) "Electromagnetic waves (EMW)" means all "Light" waves and all electromagnetic radiations from 530 kHz to 1 THz;

(12) "Wave" mean means all EMW and ultrasonic waves;

(13) "Information carrier" means RF wave or ultrasonic wave on which the information is ridding; while "carrier wave" means the light wave or millimeter microwave on which the RF is ridding (i.e. RF modulation);

(14) The term "in a space" or "in image space" means on 2D flat surface or 2D curved surface, or in our real space (3D). It is a well-known knowledge that 1D, is a line, 2D space is 2D plane and 3D space is our real space;

(15) The term "computer" means a programmable device (i.e. a generalized computer) for system and embodiment controlling.

(16) 'phase detector' means a mixer or a digital phase detector;

(17) "hand stick" means a device which provides the power to head-carrier for making head-carrier moving, it could be either hand-hold apparatus or powered-apparatus,

<SYSTEM CONSTITUTION >

[paragraph 1] Herein below are described the constitution and operation of the system, apparatuses, and the methods for positioning, processing and controlling, in detail with references to the accompanying drawings.

[paragraph 2] FIG. 1 is used here to show the constitution of one of the preferred embodiments for the wave-based image reproduction and recording systems according to the invention. The system reproduces the image on the image area 10 of a surface based on image

data stored in computer 900, or record the image data from image area 10 into computer 900, by causally pushing and pulling the "hand stick" 102 of head carrier 100 (or any hand hold brush like body) , on the surface. The surface can be any surface, such as curved surface, sphere surface, etc. The head carrier can be a hand-operational apparatus with a "hand stick" 102, or can be a powered-apparatus-aided apparatus for huge applications, or can be robot operation, or vehicle carried operation , if the environment of operation is not accessible for human being.

[paragraph 3] For image reproduction, four communication units (CU) 201 ~ 204, used as the transmitters / receivers with marks (A1, A2, B1, and B2), are set at the four corners. The CU (details in FIGS. 3 ~ 7 later) set on the head holder 300 are used as the receivers / transmitters, respectively. The information carrier can be either radio frequency (RF), or light from T-ray to X-ray, or ultrasonic wave. However, if RF is directly (i.e. not modulation) used as information carrier, the CU must be set at corners or edges and must be fairly far away from the boundaries of image area 10, due to the nonlinearity of phase dependence of the near-field.

[paragraph 4] For convenience, the case of using the CU 201 ~ 204 as the transmitters and using the single CU (head locator) on head holder 300 as the receiver is described here first. The operation unit (OU) 400 produces signals and sends signal to CU 201 ~ 204, through cables 51,52, 61,62. The cables 51 and 52 are split from one source, and have the same length from the splitter 50 to A1 201 and A2 202, so that they have the same time delay. The same is applied for cables 61, and 62; they have the same length from the splitter 60 to B1 203 and B2 204. The CU 201 ~ 204 transmits the waves out. The receivers receive the waves with phase or time information and send the message back to the OU 400 through cable 20. The hardware in operation unit 400 processes the message and converts the message into phase difference or time difference, and sends these data to computer 900 through cable 40. From these phase data, computer 900 inverses the coordinates of the position of the head locator (details in FIGS. 3,4,5) on head holder 300 by using positioning theories and formulas of this invention. According to the head position coordinates, computer 900 searches the nearest pixel to this position in image data file and takes the color data of this pixel, and sends the data to OU 400 through cable 40. Then OU 400 sends action commands and power to spray head on head holder 300 through cable 30. Any pixel on screen of computer 900, of which the corresponding image has been reproduced on the image area 10, will be marked by computer 900 and will not be reproduced again if the head on holder 300 moves back to the same position later.

[paragraph 5] For image recording, an image reader or reader array is installed on the head holder 300. The positioning procedures are the same as that for image reproduction, described above. Triggered by the trigger clock, the coordinate information and color data are taken from the image area 10 at the triggered moment and are sent back to computer 900 through OU 400. Computer 900 processes the information and data promptly or stores them into a file for overall processing lately. Computer 900 inverses the signal that carries the coordinate information into coordinates. The coordinates at the triggered moment may not be just at a pixel in the pre-formatted pixel grids. So computer 900 then calculates the color values at all pixels in pre-formatted pixel grids from the obtained coordinates and color data, by using interpolation method.

[paragraph 6] The transmitter and receiver can be swapped. The CU 201 ~ 204, A1, A2, B1, B2, can also be used as receivers (serve as receiving CU), while the CU on the head holder 300 can be used as transmitters (serve as transmitting CU). The details will be described in sections below.

[paragraph 7] The procedures described above are applicable for the all preferred and alternative constitutions described below.

[paragraph 8] FIG. 2 shows the another preferred constitutions for 2-dimensional (2-D) applications according to the invention. The color material tanks are necessary for large images and are placed on the head carrier 100 (details in FIGS. 3, 4 and 5). However, for huge images, the color tanks 140,142 and 144 are placed on the ground. The color materials are transported to sprayers on the head holder 300, through tubes 130,132 and 134, as shown in FIG. 2 (a). In FIG. 2 (b) is shown an option to use only three CU at three corners, with CU A1 201 and B1 203 merged together. FIG. 2 (c) is an option to use four CU 201 ~ 204 on the middle edges, which provides the simplest positioning theories and formulas. For the time-based positioning, the embodiment shown in FIG. 2(d) is used, here only two CU A1 201 and A2 202 on bottom corners are used.

[paragraph 9] For 3-dimensional (3-D) applications, another one or two CU's need be installed at any points (except too close to the image surface) on *z*-axis of all the cases described in FIG. 1 and FIG. 2. The *z*-axis vertical to the 2-D frame plan (image surface), and it could be one edge of the 3-D frame. For all the cases described above, CU can be either fully or partially at either the middle edges or the corners of the frame, and the color tanks can be either on the head carrier 100, or on the ground.

[paragraph 10] The cables used for transmitting the phase-doesn't-matter signal, color data, and operation commands between operation unit 400 and head 300 can be replaced by wireless communication.

[paragraph 11] For the relative-motion-based system, with the optical-image approach or mouse-technique approaches, there are no CU (201 ~204) and OU 400, and the cables between them. Instead of CU and OU, MD and OM are installed together with head on head holder 300 and causally moving on the image surface. The OM (not shown in FIGs.) is directly connected with computer 900 through a multi-path cable. Computer 900 periodically sends the commands to OM. OM executes the commands to read the motion information of the locators from MD, and organizes this information as time-sequences. Then OM sends these time-sequences to computer 900 by multi paths in parallel through the cable. Computer processes the information for locator positioning and determining the coordinates of the head in the head array. The OM executes the commander from computer to control the action (spraying or reading) of the head in head array. One of the preferred MD's comprises a two-dimensional array of camera-image sensors (M by N pixels), two lenses, and one laser. For recording system, OM reads out the image information at each image pixel on sensor array, and organizes this information as time-sequences and sends them to computer 900, then computer stores this image information on disk. Also, any computer-mouse techniques can be employed as MD.

< APPARATUS CONSTITUTIONS AND OPERATIONS >

<u>Head carrier</u>

[paragraph 12] FIG. 3 shows one of the preferred embodiments for the head carrier with single head according to this invention. The head carrier 100 is composed of a frame 110 (main body of head carrier, any shape), one front wheel 112, two rear wheels 114, "hand stick" 102, head arm 106, and head holder 300. The wheels (112, 114) enable the carrier 100 moving on the image area 10 freely, and guarantee a constant fly height 301 for the head 382 (sprayer or image reader) over surface 10. The "hand stick" 102 is connected with the head carrier 100 by a joint

104, and the stick 102 can freely rotate about joint 104. The head arm 106 is connected with the head carrier 100 and can rotate about the axle 105 by hand-operation, for flexible application in different situations. The CU 381 and the head 382 are installed on the head holder 300. Head holder 300 is supported by head arm 106 at one end of the arm. For small image applications, the color materials are stored in the container built-in with the sprayer or color cartridges. For large image applications, three (or four if an additional black tank is needed for color quality) color tanks 120 (cyan), 122 (magenta), and 124 (yellow) are installed on the head carrier 100, moving together with the head carrier. The color materials are provided to the head from the tanks (120,122,124) through color tubes 130,132 and 134. For huge image applications, the color materials are provided to the head from ground tanks 140,142,144 (FIG. 2 (a)) through color tubes 130,132 and 134.

[paragraph 13] FIG. 4 is used to show one of the preferred embodiments for the head carrier with head array according to this invention. The differences of this head carrier from the one described in FIG. 3 are in the head holder 300 and head cartridge 385 (instead of single head). A number of heads are built on the head cartridge 385 and form a head (sprayer or reader) array 386. The image resolution (IR) is determined by head density in head array, which is determined by the number of heads in the array and the array length L1 (391). Two CU (383, 384) (i.e. two head locators) are installed on the head holder 300. The holder extension 303 is needed to hold one of the CU, 384, so as to extend the distance L2 (392) between two locators, 383 and 384. The purpose of this extension is to increase the accuracy in position determination of each head in the head array 386. The extension 303 can be added to either side of the head holder 300, depends on the convenience. The head holder 300 can rotate about the axle 302 by hand-operation, by 360°, for different situations of application.

[paragraph 14] FIG. 5 is used to show another preferred embodiment for the head carrier with sprayer array built-in an ink-jet cartridge according to the invention. The only difference from the one described in FIG. 4 is that a color ink-jet cartridge 389 with sprayer array 390 is now used.

<u>Communication Units</u>

[paragraph 15] The preferred options for transmitting CU (transmitters) according to this invention are shown in FIG. 6, including (a) Radio frequency (RF) antenna 610, (b) single light source (Laser or LED) 630, (c) four light source 640, and (d) ultrasonic transmitter 620.

[paragraph 16] The RF antenna 610 is used as the transmitter for RF-based system design. The wavelength of RF that it radiates equals the dimension of image area 10. Here is an example: dimensions 100 meters, 30 meters, 3 meters, 10 centimeters and 1centimeter are corresponding to RF frequency 3 MHz, 10 MHz, 100MHz, 3 GHz, and 30 GHz, respectively. If the technique for current-phase wrapping processing is used, the frequency can be higher.

[paragraph 17] For applications with larger image area, the lower frequency is used. Therefore, the RF can be carried on (i.e. modulates) some extremely high frequencies -- millimeter microwave, where the frequency allocation is empty and the use of frequency is unlicensed (such as those at peak absorption of atmosphere), so as to avoid to be interrupted with public communication and military frequencies. In these cases, the same procedures as that used in light-based system described below are applicable, except the generator, transmitter, and receiver of carrier wave.

[paragraph 18] For the light-based systems, the RF is carried on the light wave by amplitude modulation or frequency modulation. The light is emitted from the emitter 632, called single-light transmitter. For 2D application, by a cylindrical lens 634, rather than by a spherical lens, the light is uniformly divergent to the region with an angle 636 (any angle between 90^0 and 150^0 is applicable, but 110^0 is preferred). The design of lens and light direction makes the light divergent as less as possible in the direction vertical to the paper plan. The single-light transmitter 636 is used for the system of which the transmitters are installed at the corners of the image plan. Four-light transmitter 640 is built by four of single emitter 630, and is used for the systems of which the transmitter is installed on the head holder 300. The ultrasonic transmitter 620 is employed for the time-based systems. For 3D application, the lens is spherical and the six-light transmitter is used.

[paragraph 19] FIG. 7 is used here to show the preferred embodiments for receiving CU (receivers) according to this invention: (a) RF antenna 710, (b) single-photo-detector 720, (c) two-photo-detector receivers 730, (d) four-photo-detector receiver 740, (e) corner single-photo-detector 750, (e) corner single-photo-detector with a curved substrate 760, and (g) ultrasonic receiver 770. Due to the reciprocal principle of electromagnetic theory, those described in RF

transmitters above are applied for RF receivers 710. The RF that is carried on an extremely high frequency (millimeter microwave) is demodulated by heterodyne or homodyne techniques.

[paragraph 20] For the systems of which the receiver is on the head holder 300, the two-photo-detector receiver 730 (three-photo-detector for 3D), or the four-photo-detector receiver 740 (and six-photo-detector for 3D), is used. They are built from a single-photo-detector 720. The latter is made up of photo sensor (photo detecting material) 728, light wavelength-selection filter 726, and cone mirror 724. The cone mirror 724 reflects the light 722 from all directions to the filter 726 and photo sensor 728. The current signal is generated from the sensor and is sent to the operation unit 400. Inside the sensor, a pre-amplifier may already be built in.

[paragraph 21] For the systems of which the receiver is at the corner of the image plan, the single corner photo-detector 750, or the one with a curved substrate 760 is used. The light 752 from different directions is focused on the photo-sensing material 728 by the lens 754, so as to increase the sensitivity, as shown in FIG. 7 (e) and (f). Before sensor, there is also an optical wavelength-selection filter.

[paragraph 22] The ultrasonic receiver 770 is employed if the ultrasonic transmitter 620 is used in the system.

Motion Detector and Operation Module

[paragraph 23] For the relative-motion-based system, the head includes a motion detector (MD), an operation module (OM), and a sprayer or/and a reader. The preferred apparatus for the MD is the detector of optical image motion (340), as shown in FIG. 8. The MD is built together with the sprayer head 350 or/and recording head (not shown in the figures). The container 359 in sprayer head 350 is a buffer for ink or paint material, which provides the ink or paint material for the sprayers in sprayer array 352. The optical image motion detector 340 comprises laser 341, lenses 342, 344, and camera pixel sensor array 346. The laser 341 is installed at a focus of the lens 342, so the light is converted into parallel light beams and projects onto the surface of the path of head locator on image area 10. By lens 344, the optical image of the object (a 'micro' texture) 343 (any patterns, roughness distribution on the surface) appears on the surface 345 of the camera pixel sensor array 346. The light paths 348 for the image system are shown on the right side. The distance between the object 343 and the center of lens 344 is beyond two focus length of lens 344, while image 345 of the object is in between one and two of the focus length.

The OM with a small volume (not shown in the figures) is installed together with the sprayer/reader and MD. OM executes the commands from the computer to read the motion information from MD, and organizes this information into time-sequences. Then OM sends these time-sequences data to the computer by multi-paths in parallel. OM also executes the commands from the computer, after the computer finishes the processing, to control the action of the head.

[paragraph 24] For the recording system, the constitution is the same; the sprayer-array is replaced by the reader-array.

< SYSTEM OPERATIONS>

[paragraph 25] The procedures of controlling and processing for one of the RF-based system according to the invention is shown in FIG. 9. The RF is directly used as the information carrier. The functions of operation unit (OU) 400, of computer 900, and of head 300 are shown in the frames of the left dish-line 401, the right dish-line, and the top dish-line, respectively. Before the system goes to work, the distributing signal and noise detector 411 searches the low noise RF channels. According to the channel selection 412, the frequency ω (higher) and $\Delta\omega$ (lower) is determined (using these two frequencies, the frequencies $\omega_1, \omega_2, \omega_3, \omega_4$ for four RF channels are generated). The oscillators 413 and 414 are tuned to these two frequencies, and amplified by amplifiers 415 and 416. The higher frequency is split into three by splitter 417. Two of them are sent to mixers 419 and 420 and one of them is sent to frequency doubler 422 and then to a switch 423 (optional). The lower frequency is also split into three by splitter 418. One of them is sent to mixer 420 directly and the second is sent to mixer 419 after frequency doubler 421. The third one is sent to a switch 423, which is connected to phase processor 430. The two mixers provide the sum and differences of the two inputted frequencies. With filters 424, four frequencies ($\omega_1, \omega_2, \omega_3, \omega_4$) are separated and are sent to four transmitting antennas 211 ~ 214 at A1, A2, B1 and B2 shown in the previous figures. All four RF channels are amplified by amplifiers, 425. The receiver 311 receives the four signals from the four transmitters (411-414). After the band amplifier 426, the amplified four signals are split into four paths by splitter 427. The band pass filters, 428, allow only one frequency pass through each one of them. Phase processor 430 decodes the phase differences between A1 and A2, and the phase differences between B1 and B2, if the switch is turned to down side. Or, phase processor 430 decodes the phase sums of A1 and A2, and the phase sums of B1 and B2, if the switch is turned

to up side. More details about the phase processor are described later with FIG. 11. Phase calibration can be done by either the software in computer 900, or by the phase calibrator 431 before signal goes into computer 900. The same procedures for signal processing are applied for the receiver on the second locator shown in FIG. 4 (384) or in FIG. 5 (388). Computer 900 receives two groups of the phase messages for the positions of the two head locators (i.e. the antenna receivers), (432,433) and (444,445).

[paragraph 26] Computer 900 processes the phase data by inverting the coordinates of the positions of the two locators from the phase data, which is based on the positioning theories and formulas of this invention. According to the coordinates of the two locators, computer 900 calculates the coordinates of each of the head in head array (386, in FIG. 4) by using interpolation method. According to the position of each head, the computer 900 searches the nearest pixel in the image data file to this position and takes the color data of this pixel, and sends the data to control unit 429. Then the control unit 429 sends the action commands and power to head 308 through color cables 306 and power cable 307.

[paragraph 27] FIG. 10 shows the procedures of controlling and processing for another RF-based system according to the invention. The difference here is that the transmitter and receiver are swapped from the system described in FIG. 9. The four RF channels are combined together by combiner, 434, before being sent to the transmitting antenna 321. The four receiving antennas receive the signals and send the signals to four band-pass filters, 435, which allow only one frequency to pass through each one of them. The four channels are then sent to phase processor 430 after being amplified by amplifiers, 436.

[paragraph 28] One procedures of phase processing for the RF-based systems are shown in FIG. 11 (a), the first two frequencies are conducted to mixer 4301, which produce another two frequencies, the sum and difference of inputted frequencies. The band pass filters 4303 filter out the sum frequency. At this point, the signal with the difference frequency carries the phase difference between A1 and A2. The digital phase detector (DPD) or mixer 4305 decodes the phase difference by homodyning with the signal from 423. The phase difference 4315 (A2-A1) is sent to the computer. The same is applied for the other two frequencies. The output phase difference 4314 (B2-B1) is sent to the computer.

[paragraph 29] Another phase processing procedure for the RF-based systems is shown in FIG. 11 (b). The largest and the smallest frequencies are conducted to mixer 4307, which also

produces two frequencies, the sum and difference. But the band pass filters 4309 filter out the difference frequency, rather than sum frequency. At this point, the signal with the sum frequency carries the phase sum of A1 and A2. The digital phase detector (DPD) or mixer 4311 decodes the phase sum by homodyning with the signal from 423. Then the phase sum 4317 (A2-A1) is sent to the computer. The same is applied for the two middle frequencies. The phase sum 4316 (B2-B1) is sent to the computer.

[paragraph 30] FIG. 12 shows the procedures of control and processing for one of the modulation-based systems according to this invention. In this system, RF is used as modulation. The carrier wave of this RF wave is light or millimeter microwave. For the millimeter microwave carrier, the frequency with peak absorption (60~70 GHz, 120~130GHz, and 170~180 GHz, for example) is preferred but not limited, where the frequency allocation is empty and the use of frequency is unlicensed, so as to avoid to be interrupted with public communication and military frequencies. Here, the laser, as carrier-wave, is used for illustrations. The laser driver 437 provides four currents to four lasers (231~234) to emit four wavelengths or frequencies $\Omega_1,\Omega_2,\Omega_3,\Omega_4$. The lights from all lasers are modulated by the same RF signal with frequency ω. This RF signal is generated by the RF oscillator 413 and amplified by amplifier 415. The RF splitter 438 splits the RF signal into four paths and sends the RF to each laser (231~ 234), so that the light power or light frequency is modulated. The four-detector receiver 331 converts the light power into RF currents (either coherent or non-coherent detection is used, but here using non-coherent as example). Each of the detectors has a different optical filer (726 in FIG. 7) to allow only one of the four frequencies $\Omega_1,\Omega_2,\Omega_3,\Omega_4$ to pass through. The currents are sent back to the four RF band pass filters 439 to pass RF frequency ω. After amplified by amplifiers 440, the phase differences of first two signals and the last two signals, 433 and 432, are recovered by DPD 441 and 442, respectively, and are sent to computer 900. If the mixer is used at 441 and 442, the filters 443 are needed, before the signals are sent to computer 900, for filtering out high frequency if the phase difference is used, or for filtering out the low frequency if the phase sum is used.

[paragraph 31] In the cases of using millimeter microwave as the carrier wave, the same procedures for controlling and processing in the light-based systems described above and below are applicable, except for the generator, transmitter and receiver of carrier wave.

[paragraph 32] In the cases of using a mixer at the last step before the message goes into computer 900 above and below, the message is not directly the phase difference or phase sum, but

is the sinusoidal function of them. So the computer software converts the message into phase difference or phase sum for these cases.

[paragraph 33] The procedures of control and processing for another light-based system, but with two wavelengths, are shown in FIG. 13. The transmitters 243, 244 at A1 and A2 emit the same light wavelength (or frequency Ω_1), while transmitters 241, 242 at B1 and B2 emit the same frequency Ω_2. One of the two receivers, 341, filters out the second light frequency and detects the two signals that are carried by the first frequency Ω_1 (from A1 and A2), and then sends the two detected RF signals to a RF band pass filter 448. The two signals are internally homodyned at mixer 452 after the amplifier 450. The output from the mixer 452, after a low pass filter 458, is a sinusoidal function of the phase difference, which is sent to computer 900. The other receiver, 342, filters out the first frequency and the sends the two detected RF signals (from B1 and B2, and carried by the second frequency Ω_2) to a RF band pass filter 449. The dish-line-framed part (446, 454, 455, 456, 457) is an option for using the phase sum.

[paragraph 34] The control and processing of another light-based system, with four wavelengths, is shown in FIG. 14. The difference from the system described in FIG. 12 is that the transmitters and receivers are swapped. The four-light-source transmitter 341 is installed on the head holder 300. Four corner receivers 241 ~ 244 are used.

[paragraph 35] FIG. 15 is a schematic block diagram of the control and processing of another light-based system. All the procedures for this system are the same as that in the system described in FIG. 14, except that only two wavelengths or frequencies are used.

[paragraph 36] The system with its alternatives described in FIGS. 9 to 15 is based on the phase measurement approaches, called phase-based system. The system can be also based on the time measurement approaches, called time-based system. The information carrier for the time-based system is, usually, ultrasonic wave, but it can be also any kind electromagnetic wave (light, or millimeter microwave) as long as we have fast-enough clocks in the future or for huge applications. Here, the system is illustrated by an ultrasonic-based approach as shown in FIG. 16 and FIG. 17. The clock 475 sends periodic commands (triggers) for the pulse generator 476, which generates a pulse-modulated current with an ultrasonic frequency. After the current power is amplified at amplifier 477, the current is sent to transmitter 371. The ultrasonic pulse is transmitted out from transmitter 371 and is received by receivers 271 and 272. In the meantime, the power amplifier 477 has also an output signal for the start trigger 478 to trigger the time

counters 480 and 481, so as to start time- counting at the moment the ultrasonic wave is sent out. After the receiver 271 and 272 receive the pulse, the signal is immediately (speed of electrical is far greater than the speed of sonic) amplified by the amplifiers 482, and is sent to triggers 484 and 485 to stop the time-counting. Then the time counters 480, 481 send the time differences to computer 900. The ultrasonic frequency filters 483 are used to distinguish the pulse from the other transmitters (384 in FIG. 4, or 388 in FIG. 5) on head holder extension 303 in FIG. 4, because the two transmitters are driven by different ultrasonic frequencies.

[paragraph 37] FIG. 17 is used to show the control and processing of the time-based system with another ultrasonic-based approach. The difference from the system described in FIG. 16 is that the transmitter and receiver are swapped. More clearly, the receiving CU 381 is on the head holder 300 rather than the transmitting CU on the head holder. Two ultrasonic pulse generators 488 and 489 are used to produce two driving currents with different frequencies. Therefore, the two ultrasonic pulses with different frequencies are transmitted from the transmitters 281 and 281. The mixed signal from receiver 381 after amplified by amplifier 498 is split into two paths by splitter 495. Each of the filters, 496, or 947, blocks out the other frequency and sends the pulse to triggers 484 and 485 to stop the time-counting.

[paragraph 38] The Doppler effect is an alternative used for relative motion detection. Only two transmitting CU (transmitters) at the bottom corners (such as A1, A2 in FIG. 2(d)) and two receiving CU (receivers on the head holder) as two locators are used. Instead of producing pulse-modulated PULSES ultrasonic wave or electromagnetic wave, the generators 488, 489 in FIG. 17 generate an oscillation current with two frequencies a fair away from each other, and the transmitters 281, 282 in FIG. 17 radiate CONTINUOS ultrasonic waves or electromagnetic wave. Receiver, 381 in FIG.17, is replaced by a Doppler-Frequency-Detector. When receiver 381 is moving around in the two wave-fields, the Doppler frequencies, which carries the information of two velocity components along two directions, are detected. One direction is from one transmitter A1 (281) to the receiver 381; the other direction is from the other transmitter A2 (282) to the receiver 381. So the angles of two directions are timely changing while receiver 381 is moving. The Doppler frequencies are sent to computer 900. Computer 900 converts the two Doppler frequencies into velocity components and calculates the two displacement components of the receiver (i.e. locator) by integrating the velocity components. Then from the displacement components, the relative position of the locator is determined.

[paragraph 39] The other alternative of image reproduction and image recording system is to use any mouse-technique-based positioning method for determining the relative position of the locator.

<COMPUTER PROCESSING >

[paragraph 40] INTRODUCTION --- Computer processing procedures are classified into two cases: using phase difference, or using phase sum. Also, there are two kinds of phase dependencies on the coordinates of the point in the image area 10. For modulation-based systems described above, the phase dependence on the coordinates is linear; while for the RF-based systems described above, the dependence is nonlinear due to phase nonlinearity of the near-field and the distortion from the boundary conditions. For the case of linear phase dependence and using phase difference, the contour curves for constant phase differences are a class of hyperbola curves, as show in FIG. 18(a). While, for the case of linear phase dependence and using phase sum, the contour curves for constant phase sum are a class of ellipse curves, as show in FIG. 18(b). All the hyperbolas or ellipses have the common foci at four CU's (A1, A2, B1, B2), this is the general conclusion whenever the CU's are located at the corners or at the four middle edges. This invention provides the general theories, relations, and formulas for all cases: linear or nonlinear, phase difference or sum. This invention also provides the general calibration method for the case of distortion from the boundary conditions, or nonlinearity. Computer processing is based on these theories and formulas.

[paragraph 41] CALIBRATION and INITIALIZING (1) --- The communication units, 381 in FIG. 3, 383 and 384 in FIG. 4, 387 and 388 in FIG. 5, are also called head locators as mentioned before. Usually there are two locators in the image reproduction and image recording system of this invention. With the first locator, the second is used for determining the head array direction, so that the position of each head in the head array is determined. The computer processing procedures, by using phase difference (rather than sum) and linear (rather than nonlinear) phase dependence, and for the case of only one locator, are described here first for a convenient understanding of this invention. A schematic block diagram for the illustration is plotted in FIG. 19. The procedure starts with initialization: calibration and initializing image status of the pixels. First of all, check the status of the calibration -- 911. If the calibration is not done, put the locator at (0,0), the center of the image area 10, and read out the voltage (or current)

for phase differences (PD) (between A2 and A1, and between B2 and B1) from the receiver -- 912. Usually, at this point, the PD is not zero. The zero-PD calibration at (0,0) can be achieved either by hardware (phase shifter) adjustments, or by computer processing. FIG. 9 shows an example of phase shifter 431. By adjusting the phase shifter, the PD at (0,0) can be reduced to zero. If by computer processing, these two non-zero PD's will be stored for later use – 913. Next put the locator at any corner of the image area and read out the PD – 914. Procedure 915 calculates the PD changes and distance differences (DD) when the locator moves from the center to the corner. The DD are defined as the difference of the two distances: the distance between A1 (or B1) and the head locator, i.e. r_{A1} (or r_{B1}), and the distance between A2 (or B2) and the head locator, i.e. r_{A2} (or r_{B2}), -- 915. Then the calibration coefficient is determined by the ratio of DD over PD change -- 916, which is the proportional coefficients between DD and PD change, and is used for converting the PD change to DD during the operation. The final step of initialization is to initialize image status by setting all *P(i) =0* (*i* denotes the *i*-th pixel) -- 917. The computer also figures out the scale transformation between the image area 10 and the image source stored in computer. According to the size of the image area 10, the computer will produce a frame on the computer screen according to the scale, and the operator can move the frame on the screen to the source area that he will most likely to reproduce. The status of any pixel outside the frame is initially set to 1. However, it is initially set to 0 if the pixel is inside the frame. For any pixel of which the corresponding image has been reproduced on the image area 10, the status *P(i)* will be changed to 1 from 0. If the status of a pixel is 1, the image of this pixel will not be reproduced again during the head causally moving. However, multiple reading from same pixel and overwriting the old reading doesn't matter.

[paragraph 42] CALIBRATION and INITIALIZING (1) --- If calibration is done, then jump over the calibration block (the left dish-line frame) and wait for the commands (a trigger) for taking the phase information -- 920 that is sent from the phase processor, such as the one 430 in FIG. 9. By using the PD at (0,0) and the calibration coefficient, the two DD's are determined -- 921.

[paragraph 43] COMMON PROCEDURES OF COMPUTER PROCESSING (1) --- Procedure 922 and hereafter are the common procedures for different cases: linear or nonlinear phase dependencies, using phase difference, or phase sum, or time difference. Procedure 922 is to solve the roots of an equation that includes the DD data, and gives the locator position (x, y). The

equations are different for the different cases listed at the beginning of this paragraph. Procedure 923 takes all the stored image data 924. Then checks the status of each pixel – 925. If the pixel has been sprayed (P *(i) =1)*, the next pixel is checked. If all the pixels have been sprayed (all *P(i)=1*), good job is down, and stop -- 926. If there is at least one pixel with status *P (i)=0*, then to tell how close this pixel to the locator position (x, y) – 927. If the distance is less than or equal to the criteria (1/20 ~ 1/4 of the pixel spacing is preferred), then procedure 928 takes the color data of this pixel from the image file 924, and then sends the commands for spraying – 929. Meanwhile, procedure 928 sets the status to 0 for this pixel. If the distance is greater than the criteria, then check the next pixel with status 0. If there is no such pixel that satisfies this condition at all, then it will wait for the next trigger for the next chance --930 of meeting a pixel that is spray-able, during head causally moving.

[paragraph 44] COMMON PROCEDURES OF COMPUTER PROCESSING (2) --- Of course, as shown in the right dish-line frame, there are alternative procedures (932, 933, 934) for improving the efficiency with a cost, if there is no such a pixel (i.e. it's distance from present position of the locator is less than the criteria) at all. Two fast-response micro-motors (not shown in Figures) are used to slightly adjust the head position. Procedure 933 finds the pixel in the image source which is the nearest to the locator position (x, y) at the moment. The computer predicts how much the head should be moved to that pixel, by taking in the account the velocity of the head motion and the response time of the micro-motors-driven head, and then move the head to that pixel -- 934.

[paragraph 45] POSITIONING OF EACH INDIVIDUAL HEAD IN HEAD ARRAY --- For the case with two locators, the calibration is made for each of the two locators first -- 935 and 936 in FIG. 20. After the two pairs of calibration coefficients are obtained for the two locators, the status of each image pixel in the image source is initialized to 0 --937. Now the computer takes the phase information from the two locators – 938, then the two pairs of DD (distance differences) for the two locators are calculated by using the calibration coefficients --939. In the same way as in the one-locator case, the position coordinates of the two locators, ($x^{(1)}$, $y^{(1)}$) and ($x^{(2)}$, $y^{(2)}$), are obtained – 940, and the status of each pixel is checked – 941, 942, 943. If all the pixels have been sprayed/read (all *P (i)=1*), stop -- 944. Otherwise, the program uses interpolation method to determine the position coordinates of each head along the head array -- 946: $x(j) = x^{(1)} + D_x \times (j-1)$, $y(j) = y^{(1)} + D_y \times (j-1)$, $D_x = (x^{(2)} - x^{(1)})/N$, $D_y = (y^{(2)} - y^{(1)})/N$.

Here N is the total number of head along the head array, and j $(=1,2,..., N)$ denotes every head. Procedure 947 checks every head $(j=1,2,..., N)$ on the array --- if the distance between any head and any pixel is less than the criteria? If yes, the computer takes the color data from that pixel and set status to 1 – 948, and then commands that sprayer to spray – 949. Procedure 951 in the dish-line frame is an alternate for improving the efficiency, if there is no such pixel at all, or if there is only one such pixel. In this case, three fast-response micro-motors are used to slightly adjust the sprayer array position and direction, so that each sprayer on the array can aim at a corresponding pixel. Two motors are installed at the end of the array [at the side of locator 383(FIG. 4) or 387(FIG.5)], and the third motor is installed at the other end of the array [at the side of locator 384 (FIG. 4), 388 (FIG.5)]. The third motor drives the head array rotates about axle at the first sprayer. Similar to procedure 933 in FIG. 19, the computer find out the pixel in image source which is the nearest to the position ($x^{(1)}$, $y^{(1)}$) of locator 1 at that moment (this is also the position of the first sprayer --- this is just a corresponding relation, not necessarily physically the same). The computer predicts how much the array should be moved to aim at that pixel, by taking in the account the velocity of head motion and the response time of micro-motors-driven spray head, and then move the array so that the first sprayer aims at that pixel. Meanwhile, the computer predicts how much the array should be rotated to make each of the sprayers aim at a corresponding pixel, by taking in the account the moving trend and inertia. Then the micro-motor rotates the array to the predicted angle and computer commands the sprayers to spray.

[paragraph 46] INVERTING THE LOCATOR'S POSITIONS BY SOLVING EQUATIONS --- For the modulation-based method, the phase has a linear dependence on the distance (r) between the receiver and the transmitter. For the given two pairs of detected phase difference ($\Delta\varphi_A$ = phase of A2 – phase of A1, and $\Delta\varphi_B$ = phase of B2 – phase of B1), or phase sum ($\Sigma\varphi_A$ and $\Sigma\varphi_B$), the position coordinates (x, y) of the locator are the roots of the equations $(x\cos\theta_1 + y\sin\theta_1)^2\ /a_1^2 - (-x\sin\theta_1 + y\cos\theta_1)^2\ /b_1^2 = 1$ and $-(x\cos\theta_2 + y\sin\theta_2)^2\ /b_2^2 + (-x\sin\theta_2 + y\cos\theta_2)^2\ /a_2^2 = 1$. When A1, A2, B1, B2 are at the corners, θ_1 is the angle between the line A1-A2 and the right direction of the horizontal line and $\theta_2 = 90 - \theta_1$. However, when A1, A2, B1, B2 are at the middle edges, θ_1=0 and $\theta_2 = 0$. For the phase difference approach, $c_1 = D_{A2-A1}$ (distance between A1 and A2, same meaning hereafter), $c_2 = D_{B2-B1}$,

$a_1 = c_1 - k_A \Delta\varphi_A$, $a_2 = c_2 - k_B \Delta\varphi_B$. For the phase sum approach, $c_1 = 0.5D_{A2-A1}$, $c_2 = 0.5D_{B2-B1}$, $a_1 = 0.5k_A \Sigma\varphi_A$, $a_2 = 0.5k_B \Sigma\varphi_B$. For both cases, $b_i = \sqrt{c_i^2 - a_i^2}$ ($i = 1,2$). For the phase difference approach, b_i is a pure real number, and the contour curves for constant phase differences are a class of hyperbola curves, and the right root-pair (x, y) is uniquely distinguished from the four pairs of the roots by checking the signs of the two phase-differences. Here is an example: consider the case A1-A2 is vertical to B1-B2, as the cases shown in FIG. 2(b) and (c). The phase information ($\Delta\varphi_A < 0$ and $\Delta\varphi_B < 0$) corresponding to the solution with (x > 0, y > 0); ($\Delta\varphi_A < 0$ and $\Delta\varphi_B > 0$) ←→ (x > 0, y < 0); ($\Delta\varphi_A > 0$ and $\Delta\varphi_B < 0$) ←→ (x < 0, y > 0); and ($\Delta\varphi_A > 0$ and $\Delta\varphi_B > 0$) ←→ (x < 0, y < 0). While, for the phase sum approach, b_i is a pure image number, and the contour curves for constant phase sum are a class of ellipse curves, and the right root-pair (x, y) cannot be distinguished from the four pairs of the roots by using the phase information. In this case, the computer program sets the region ID (identification) for the four quarter-regions (left bottom=1, right bottom=2, left top=3, right top=4). The operator inputs the locator region ID from a keyboard when the locator begins to move. The computer then changes the region ID whenever the locator moves across the region boundaries. Therefore, the right root-pair (x, y) is distinguished from the region ID and the moving trend.

[paragraph 47] INVERTING THE LOCATOR'S POSITIONS BY SURFACE FITTING --- The above procedures for modulation-based method are characterized by the linear dependencies of the phase. For the RF-based system, radio frequency (RF) is directly (i.e. not used as modulation) used as the information carrier. The phase has a nonlinear dependence on distance (*r*) between the receiver and the transmitter due to the near field: $\varphi(r) = kr - \tan^{-1}[(k^2r^2 - 1)/(kr)]$, k is propagation constant of RF wave. The coordinates of locator position can be determined by finding the minimum point of $I(x,y) = [\varphi(r_{A2}) - \varphi(r_{A1}) - \Delta\varphi_A]^2 + [\varphi(r_{B2}) - \varphi(r_{B1}) - \Delta\varphi_B]^2$, or $I(x,y) = [\varphi(r_{A2}) + \varphi(r_{A1}) - \Sigma\varphi_A]^2 + [\varphi(r_{B2}) + \varphi(r_{B1}) - \Sigma\varphi_B]^2$. Here ($\Delta\varphi_A$ and $\Delta\varphi_B$), or ($\Sigma\varphi_A$ and $\Sigma\varphi_B$), are the detected phase differences, or phase sums, respectively. The first minimization starts at the initial point that is defined by the roots of the linear equations from the linear limit (the larger *r*) of the phase dependence, and the later minimization starts at the previous position of the locator. The boundary condition of the electromagnetic filed may introduce a discrepancy of the phase

dependence from the formula above, which is determined by the environment and cannot be predicted ahead. If the discrepancy is significant, a calibration method is employed. The calibration method is to mesh the image area 10. Move the locator at each node on the mesh. The computer then records the phase difference and the coordinates of the node. Then the computer uses the surface functions to fit the coordinates versus the phase difference by using numerical methods (such as finite element method). By using these surface functions, the computer determines the coordinates from the phase difference when the locator moves to any position on the image area 10.

[paragraph 48] PHASE-CURRENT PROCESSING (1) --- For both cases of using digital phase detector (DPD) or mixer, the phase shifters built in the operation units are so adjusted that, for the zero phase (i.e. phase difference between two inputs of the DPD, or mixer), the output current is zero. The DPD outputs a linear current that is proportional to the phase (i.e. phase difference between the two inputs of the DPD) in the region $(-2\pi, 2\pi)$. However, the curve is wrapped out of this region for every 2π of increase or decrease in phase, as shown in bottom of FIG. 21. The mixer outputs a current that is proportional to the sine function of the phase. So the monotonous region is $(-\pi/2, \pi/2)$. Out of this monotonous region, there are the other monotonous regions for every π increase or decrease in phase. So usually, if the noise level is low enough, only the middle region is used for both cases. Therefore, the wavelength of the RF modulation or RF-carrier should be the maximum dimension of the image area 10 if DPD is used; while it should be 4 times of the maximum dimension of the image area 10 if mixer is used. So using the DPD will result in 4 times better signal to noise ratio (SNR) than using mixer if the noise level is same, that is, the resolution is 4 times better by using DPD than by using mixer. The minimum (or best resolution) is determined by the noise level.

[paragraph 49] PHASE-CURRENT PROCESSING (2) --- For higher resolution applications, if the noise level cannot be reduced, the current-phase wrapping needs special treatment by the computer program. For the case of using DPD, as shown in the top of FIG. 21, the phase space is divided into $(2M-1)^2$ regions, with $M=3$ as an example. This leads to M times better resolution. Each region is assigned to an identification (ID) number (ij) ($i, j = 1,2,..,2M-1$), ($i = 1, 2, ...$) denotes the number of wrapped regions for the phase difference between B1 and B2, and ($j = 1, 2, ...$) denotes the number of wrapped regions for the phase difference between A1 and A2. The computer always changes the ID number if the locator moves across the boundary and

into a new region. Therefore, before head starts moving at center region, the computer initializes ID at the center region, that is, set ID = 33, for the case as shown in FIG. 21. Then the locator is moved to the position where the operator wants to start the work, and the computer follows the regions that the locator passes and promptly changes the ID numbers. Finally, for example, the locator moves to the region 51 through a path, and the computer follows the locator and finally changes the ID number to 51 starting from 33. Now the button for active spraying is switched on and the sprayers start to work. Let's define phase-current and detected-phase-current. The detected-phase-current is the output of the DPD (the solid lines in bottom of FIG. 21). The phase-current is the processed current without wrapping and is scaled to phase (the dish lines in bottom of FIG. 21), and the phase is the phase-difference used in the next computer processing as described above. For the non-center region, the phase-current should jump a value from the detected-phase-current. As shown in FIG. 21, for regions 34 and 35, the phase-current for phase difference of A2-A1 should shift to 959 and 960, respectively, from the detected-phase-current (955 and 956). Or, in other words, in the regions 34 and 35, the phase which is directly (i.e. without shift) determined from the detected-phase-current should add 2π and 4π, respectively. If using a very large *M*, this method can also serve as an alternate for relative-motion-based system that will be described below.

[paragraph 50] PHASE-CURRENT PROCESSING (3) --- For the case of using the mixer, the procedures are almost the same, except the region size (all $\pi \times \pi$, rather than $2\pi \times 2\pi$, $2\pi \times 4\pi$, $4\pi \times 2\pi$, and $4\pi \times 4\pi$ in the DPD case) and the sine dependence of the detected-phase-current on the phase (rather than linear dependence). Therefore, the detected-phase $\Delta\varphi_d$ is determined by inverting the sine function from the detected-phase-current. The phase is transformed from $\Delta\varphi_d$, such as $\pi - \Delta\varphi_d$ and $2\pi + \Delta\varphi_d$ for the first right region and the second right region from the center region, respectively, for example.

[paragraph 51] COMPUTER PROCESSING OF TIME-BASED METHOD --- For the time-based method (i.e., based on the time measurement), the computer receives two time differences, t_{A1} and t_{A2} from the OU 400, which are the times for the pulse propagation from the CU at A1 and A2, as shown in FIG. 2(d), to the CU as head locator. Then the computer solves the root pair (x, y) from the equations $(x - x_{A1})^2 + (y - y_{A1})^2 = (t_{A1}v)^2$ and $(x - x_{A2})^2 + (y - y_{A2})^2 = (t_{A2}v)^2$. Here v is the speed of the pulse propagation. If the computer so sets the coordinate

system that $y_{A1}=0$, $y_{A2}=0$, and at the vertical central-line of the image area 10, $x=0$, then the two pairs of roots with negative y coordinates are dropped. The root (use negative sign for x if $t_{A1} < t_{A2}$, use positive sign for x if $t_{A1} > t_{A2}$) with the positive y coordinate is the solution.

[paragraph 52] COMPUTER PROCESSING OF OPTICAL IMAGE-MOTION-DETECTOR BASED APPROACH --- For the relative-motion-based method, the head includes a motion detector (MD) and operation module (OM). The preferred apparatus for the MD is the optical image-motion-detector (340), as shown in FIG. 8. The camera pixel sensor array 346 converts the optical image into electrical signals, which are sent to the computer's memory for digital processing. The head starts moving at the center of the image area 10 after the initial setting of the reference point of the relative motion at this point. At this moment, a picture is taken --- the middle panel that are shown in FIG. 22 (a) represents the windows of image 964. The position of the image 965 is defined as the left bottom corner of the window. At this moment, the image position is at 964. At the moment of the next trigger, the head is moving to the position 966 marked by the filled circle. The picture-taken frequency should be high enough so that between the two neighboring pictures, the position just changes a distance of a few pixels, even if with the fastest moving. Especially, if the head starts from static state, the position just changes a distance within one pixel. The computer starts the analysis by determining the image-correlation at assumed positions, one of the positions is at 967 for example. The image-correlation is defined as the averaged summation of squares of difference (or absolute value of difference --preferred) of light intensity at pixels over the common image area (thin dash line) of the two pictures. One of pictures is the previous picture 964, the other is preset picture 968 but at assumed position 967. So if the image-correlation is smaller, the assumed position is closer to the actual position 966. From FIG. 22 (a) and (b), the image-correlation for position 967 (FIG. 22 (a)) is larger than that for position 969 (FIG. 22(b)).

[paragraph 53] HEAD SPEED UP MOTION --- For the cases that the head starts moving or restarts to move after the speed is reduces to zero, the computer will determine the relative position of this picture 971 to the previous picture 972 in FIG. 22 (c). However, the computer does not know along which direction the head is moving. The computer calculates the image-correlation at *five* points (i.e. five assumed positions) and then uses a surface to fit five points of the correlation. Computer finds out the maximum point on the surface (or the minimum point of

the 'negative surface'), which is (or very close to) the actual position 971 of the image at the present moment. Among the five points, one point is called the surface-fitting center 972, which is, at this moment, at the previous position. The other four points are at the four nearest corners (open circles in (c)) of the surface-fitting center. Hereafter, the term "frame" represents the quadrilateral frame, of which the four corners are at the four outer points with the center at the surface-fitting center, for five-point fitting. And it represents the pentagonal frame, of which the five corners are at the five outer points with the center at the surface-fitting center, for six-point fitting below. It would be lucky if the maximum correlation point is inside the frame (as shown in (c)). If the maximum point is inside the frame but too close to the boundary, one more point 973 on the lower side of the surface is needed, and computer redoes the surface fitting by *six* points, for better accuracy. For each new position at a new trigger moment, the first surface fitting is made by always using *five* points. The second-and-after surface fitting are made by always using *six* points.

[paragraph 54] HEAD SIMPLE MOTION --- If the head is moving, the computer stores the history data of the head positions. From these data, the head movement trend (the velocity and acceleration) can be determined. Therefore, the position of next picture at the next triggered moment can be predicted at 974 (by extrapolation), as shown in FIG. 22(d), although the actual position is at 975. Then the computer finds the nearest pixel to the predicted position 974, and uses this pixel as the surface-fitting center, and repeats the procedures described in the above section (with FIG. 22(c)). If the prediction is accurate enough (i.e. head motion is not complex), the actual position (that is the maximum point) of the picture at this moment should be inside the frame. So the same later procedures described in the above section (with FIG. 22(c)) are applied. Otherwise, the computer should finish the following procedures.

[paragraph 55] HEAD COMPLEX MOTION --- The extrapolation-predictable motion is called simple motion, otherwise it is called complex motion. If head complex motion, the prediction is not efficient. Therefore, as shown in FIG. 23, the actual position (may at A or B) of the picture at this moment is out off the frame of which the center (surface-fitting center) is at 977. The center 977 is the closest pixel to the predicted position 976. This means that there is no maximum point in the frame center at 977. Therefore need RE-SETTING SURFACE-FITTING CENTER: the computer needs to compare the values of the correlation at the four corners, and picks out the point with lowest correlation value, V_c (i.e. the point 980 for the case shown in FIG.

23(a)), and picks up the values of the two neighbored corners, V_1 for 979 and V_2 for 981. Then the computer defines the two variables: $R_1 = \min\{|V_1 - V_c|/V_c, |V_2 - V_c|/V_c\}$ and $R_2 = |V_1 - V_2|/V_c$, and sets the two criteria's CR_1 (say 0.5) and CR_2 (say 0.2) which need optimization. Here $\min\{\ \}$ means taking the minimum value in the list. If $R_1 > RC_1$, $R_2 > RC_2$ and $V_1 < V_2$, then use 983 (in FIG. 23 (a)) as the next surface-fitting center. If $R_1 > RC_1$, $R_2 > RC_2$ and $V_1 > V_2$, then use 985 (in FIG. 23 (b)) as the next surface-fitting center. If $R_1 > RC_1$, $R_2 \le RC_2$, then use 987 (in FIG. 23 (d)) as the next surface-fitting center. If $R_1 \le RC_1$ and $V_1 < V_2$, then use 988 (in FIG. 23 (c)) as the next surface-fitting center. If $R_1 \le RC_1$ and $V_1 > V_2$, then use 989 (in FIG. 23 (c)) as the next surface-fitting center. This time, we don't need four points, but three or two points (thin open circles) around the new surface-fitting center will be added. The surface-fitting is carried out by six (rather than five) points, the center and the newly added points plus some old points. If using the old points [980 and 979 for the case in (a), 980 and 981 for the case in (b), 977, 980,979 for the case in (c), and 980, 979 or 981 for the case in (d)], the point 984 in (a) or 986 in (b) is not necessary. If a maximum point is found in the new frame, the actual position of the head at the present moment is obtained. Otherwise, the computer repeats the procedures until the actual position is found.

[paragraph 56] DOPPLER EFFECT METHOD --- The Doppler effect of ultrasonic or electromagnetic wave is used for positioning. Here use ultrasonic wave as an example. For the system based on ultrasonic Doppler effect, the generators 488, 489 in FIG. 17 generate the oscillation current with two frequencies a fair ways from each other, and the transmitters 281, 282 in FIG. 17 radiate continuous ultrasonic waves. Receiver 381is replaced by a Doppler frequency detector. When the receiver 381 is moving around in the two ultrasonic fields, the Doppler frequencies are detected. The two velocities (v_1 and v_2) facing the two ultrasonic wave sources are inverted from the two Doppler frequencies, respectively, by the computer. Then the displacement of the head facing the two sources can be obtained by $\Delta r_1 = \int_0^{\Delta T} v_1 dt$ and $\Delta r_2 = \int_0^{\Delta T} v_2 dt$, respectively. Here ΔT is the time spacing of the two neighboring triggers. If the head positions relative to the two sources at the moment of last trigger are $\vec{r}_{10}$ and $\vec{r}_{20}$, respectively, the head displacement is $\Delta\vec{r} = \Delta r_1 \frac{\Delta\vec{r}_{10}}{r_{10}} + \Delta r_2 \frac{\Delta\vec{r}_{20}}{r_{20}}$. Then the head positions relative to the two sources at

the moment of present trigger can be written as $\vec{r}_1 = \vec{r}_{10} + \Delta\vec{r}$ and $\vec{r}_2 = \vec{r}_{20} + \Delta\vec{r}$, respectively. Now the computer solves the root pair (x, y) from equations $(x-x_{A1})^2 + (y-y_{A1})^2 = r_1^2$ and $(x-x_{A2})^2 + (y-y_{A2})^2 = r_2^2$. The next procedures are same as that in the time-based system described above.

[paragraph 57] JUMP HAPPENS --- In relative motion method, if a jump happens to the head carrier during the its moving on the image surface due to some reason, the head needs to be put back to the center of the image area 10 for initially resetting the reference point of the relative displacement.

[paragraph 58] RECORDING SYSTEM --- For the recording system, the constitutions and procedures are the same, except that the sprayer array would be replaced the by reader array.

WHAT IS CLAIMED IS:

(**Important notice**: Various changes, modifications, alterations, decorations, and extensions in the structures, embodiments, apparatuses, procedures of operation and methods of data processing of this invention will be apparent to those skilled in this art without departing from the scope and spirit of the invention. Although the invention has been described in connection with specific preferred embodiments, apparatuses, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments and apparatuses and the appended claims are therefore intended to cover all such changes and modifications as fall within the true spirit and scope of the invention.)

1. An image generation system to generate image for use with plurality of applications, whereby one reproduces or records images and patterns on or from any surface, such as reproducing images on building wall or cliff, golf course, basketball courts, football/soccer fields, billboards, posters, portraits and paintings, industry applications (such as design blueprints), industry decorations, decoration arts (such as deposit a pattern on china arts), home painting and wall decorations, archaeological image/pattern taking and museum image/pattern backup, sculptures, etc., with a flexible operation (hand- or robot- operated or vehicle carried) , working based on a mechanical-guiding-apparatus-free positioning system, and comprising:

(A) means for providing an easy, convenient and flexible operations (hand or robot or vehicle carried) for head array freely motion over the image surface with a constant fly height, a preferred apparatus is head carrier with predetermined size and shape;

(B) head array (single head is a special case of head array) installed on head carrier, performing the action of "image generation";

(C) the said "image generation" system executing the positioning operation by using a predetermined positioning method that could be any one of the methods that claimed in this invention below and that presently widely-used (such as, those based on wheel-based techniques, inertial-based techniques, existing computer mouse techniques, etc.), whichever method is used, it will be apparent to those skilled in this art without departing from the scope and spirit of this invention;

(D) a programmable device (i.e. a generalized computer, hereafter shortly "computer") for system operation and embodiment controlling;

(E) the means of computer processing for positioning, system operation and embodiment control;

(F) the phase-does-matter signals being transmitted by cable with controlled-length;

(G) the phase-doesn't-matter signals, the information of the image and the control commands being transmitted through wires or cables, or through any kind wireless.

2. The positioning method called wave-based method and the corresponding embodiments for 2D and 3D positioning comprising:

(A) Providing communication units (CU) for transmitting and receiving signals in positioning operation, whereby the signal is a predetermined kind of waves; whereby the CU's on the image surface (rather than the CU's on the head holder) for 2D case are located at the predetermined positions;

(B) providing operation units (OU's) for supplying power, generating signals, processing signal, passing the information of position and sending control commands;

(C) a "positioning locator" for single head, which is the CU on head holder;

(D) using two "positioning locators" for the positioning of all elements on the head array, whereby the computer calculating the coordinates of each of the element in a array by using interpolation method according to the positions of the two locators.

(E) providing wave-based theories and formulas, whereby a relation between positioning information and locator coordinates being established;

(F) *system operation procedures* of wave-based method for computer programming, embodiment controlling, signal processing and locator positioning.

3. The positioning method called relative-motion-based method and the corresponding embodiments for 2D and 3D positioning comprising

(A) providing motion detectors (MD's)), together with the head array, being installed on head holder for obtaining the information of locator relative motion;

(B) providing operation module (OM) for supplying power, and passing the information of positioning and sending control commands among embodiments;

(C) a "positioning locator", which is the MD on head holder;

(D) using two "positioning locators" for the positioning of head-array element, whereby the computer calculating the coordinates of each of the element in a array by using interpolation method according to the positions of the two locators;

(E) providing relative-motion-based theories and formulas, whereby a relation between positioning information and locator coordinates being established;

(F) *system operation procedures* of relative-motion-based method for computer programming, embodiment controlling, signal processing and locator positioning.

4. The system of claim 1, wherein the means of computer processing for positioning, system operation and embodiment control of image reproduction comprising

(A) reproducing image in image space based on image data stored in the computer, by causally moving the hand-operated or robot-operated or vehicle carried apparatus, called head carrier, in the image space;

(B) the OU/OM executing the positioning operations by employing the positioning method so as to get the positioning data;

(C) the computer processing the positioning data from OU/OM and inverting the position coordinates of each head in head array;

(D) according to the position coordinates, the computer searching for the nearest pixel to this position in the image data file stored in the disk and taking the color data of this pixel, and sending the data to OU/OM;

(E) then OU /OM sending commands and power to the head to execute the actions(spraying or reading);

(F) the computer then recording the history of the image reproducing process: any pixel on the computer screen, of which the corresponding image has been reproduced in the image space, will be marked and will not be reproduced again if the sprayer moves back to the same position later.

5. The system of claim 1, wherein the means of computer processing for positioning, system operation and embodiment control of image recording, comprising the common means as

that in image reproduction subsystem in claim 4 (but with image reader/reader array instead of sprayer/sprayer array) and the following exceptions:

(A) the heads taking the image digital data from image space while causally moving in the image space by the hand-operation or robot-operation or vehicle carried apparatus;

(B) trigged by a trigger clock, the coordinate information and color data are taken from the image surface at the triggered moment and are sent back to computer;

(C) the computer processing the position information promptly or storing them into a file for processing lately;

(D) the computer inverting the position coordinate information into coordinates;

(E) the computer calculating the color values at all pixels on pre-formatted pixel grids based on the obtained coordinates and color data, by using interpolation method, in case that the coordinates at the triggered moment is not just at a pixel in the pre-formatted pixel grids.

(F) the image recording system being built with image reproduction system in claim 4 as a combined system, or being built individually as a separated system.

6. The system of claim 1, wherein a preferred head carrier comprising the following embodiments and the alternatives:

(A) main body of the head carrier with a predetermined structure and shape mentioned in this invention (also including hand-hold brush-like, or the like);

(B) "hand stick", providing freely hand-operation (for the cases of not robot-operated or not vehicle carried), for flexible application in plurality of situations;

(C) head arm with the feasibility for flexibly hand-forced rotation, providing flexibility for application in plurality of situations;

(D) head holder with the feasibility for flexibly hand-forced rotation, providing support for head array, controlling or processing apparatuses, and providing a flexibility for application in plurality of situations;

(E) the said main body with at least two wheels, droved by hand or robot or carried by vehicle, enabling the head carrier moving on the image surface freely, and guaranteeing a constant fly height of head over the image surface;

(F) a container for storing the deposition materials being built on the head carrier for smaller applications; or being put on the ground for large applications;

(G) for single head positioning, only one locator being used, whereby one frequency or a group of frequencies is used for this locator

(H) for positioning of the heads in a head array, two locators being used, and a second frequency or a second group of frequencies is used for the second locator.

(I) powered micro-motors being installed on head holder for 'micro' adjusting the position and direction of head array for operation efficiency, when necessary.

7. The wave-based method of claim 2, wherein one of the alternatives, called phase-based method and working on the phase detection of the radio frequency (RF) waves with a group of frequency (2 to 6 frequencies for 2D and 3D applications);

whereby the RF could be either directly used as the carrier of positioning information or used as the carrier of positioning information through riding on the carrier waves.

whereby, 'RF riding on the carrier waves of RF' means the carrier waves are modulated by RF through either amplitude modulation (for non-coherent) or frequency modulation (for coherent and non-coherent).

8. The wave-based method of claim 2, wherein another of the alternatives, called time-based method and working on the difference detection of arriving time of the pulses;

whereby the pulse could be either ultrasonic wave pulse or electromagnetic wave pulse.

9. The relative-motion-based method of claim 3, wherein the optical image-motion-detector, as one of the alternative embodiments of motion detector (MD), comprising

(A) one light source, for providing the light for detector to 'see' the 'micro' texture (any patterns, roughness, or texture on the surface) along the path of the head locator;

(B) the first lens, for converting the light into parallel light beams and projecting onto the surface of the path of head locator;

(C) the second lens, to make the optical image of the 'micro' texture onto the surface of the sensor array;

(D) a two-dimensional array of image, for taking the picture of the 'micro' texture along the path of the head locator during head motion and sending the 'micro' pictures to computer through the OM for data processing and head positioning;

whereby, the sprayer/reader head is built together with MD, and sprayer head contains a container that is a buffer for ink or paint material and provides the ink or paint material for the sprayers in sprayer array.

10. The relative-motion-based method of claim 3, wherein ultrasonic Doppler-frequency detector as another of the alternative embodiments of motion detector (MD), comprises Doppler-frequency detector on the head locator to receive the two Doppler-frequencies of two continuous ultrasonic waves with two frequencies emitting from two ultrasonic transmitters,

whereby, Doppler-frequency carries the information of two velocity components along two directions, which are detected during the receiver is moving around in the two wave fields, and are sent to computer for determining the displacement components and the relative position of the locator;

whereby, the sprayer/reader head is built together with MD, and sprayer head contains a container that is a buffer for ink or paint material and provides the ink or paint material for the sprayers in sprayer array.

11. The wave-based method of claim 2, wherein the *transmitting* CU's are the predetermined wave transmitters and are used for transmitting the positioning signal,

whereby, each wave transmitter could be: (1) RF antenna (radiates frequency 1 MHz to 50 GHz); (2) very short microwave which is modulated by RF frequency ; (3) ultrasonic transmitter; (4) single-light transmitter; (5) four-light transmitter [for 2D]; (6) six -light transmitter[for 3D].

12. The wave-based method of claim 2, wherein the *receiving* CU's are the predetermined wave detectors and are used for receiving the positioning signal,

whereby each wave detector could be: (1) RF antenna (frequency 1 MHz to 50 GHz); (2) very short microwave antenna , being modulated by RF frequency; (3) ultrasonic receiver; (4) single-photo-detector; (5) four-photo-detector (2D); (6) six-photo-detector(3D); (7) two-photo-detector(2D); (8) three-photo-detector(3D); (8) single corner photo-detector;

whereby, the signals are either heterodyned or homodyned.

13. The method of claim 2, wherein the OU that works on the phase-based method for head positioning comprising the following embodiments:

(A) RF signal generation and transmitting section, including RF oscillators, RF amplifiers, splitters, frequency doublers, sum or difference frequency mixers, RF narrow-band filters, channel selector;

(B) carrier wave (EMW) generation and transmitting section, including a RF modulator;

(C) signal receiving and processing section, including amplifiers, narrow band-filters, one-port internal homodyne mixers, two-port phase detectors (mixers or digital phase detectors), and low-pass filters ;

(D) control unit for image data and control commands exchanging.

14. The method of claim 2, wherein the OU that works on the time-based method for head positioning comprising the following embodiments:

(A) ultrasonic signal generation and transmitting section, including pulse clock, time counting clocks, ultrasonic pulse generator, amplifier;

(B) signal receiving and processing section, including amplifiers, narrow band-filters, triggers, time counting clocks, and time counters;

(C) control unit for image data and control commands exchanging.

15. The phase-based method of claim 7, wherein the means of directly using RF comprising the following procedures of controlling and processing for :

(A) noise detector searching the RF channels with the lowest noise;

(B) the frequencies ω (higher) and $\Delta\omega$ (lower) being determined, and two oscillators being tuned to these two frequencies, and signals being amplified;

(C) based on these two frequencies, the frequencies $\omega_1, \omega_2, \omega_3, \omega_4$ for four RF channels being generated by using splitters, frequency doublers, mixers, and filters;

(D) four frequencies ($\omega_1, \omega_2, \omega_3, \omega_4$) being sent to four transmitting antennas;

(E) receiver receiving the four signals from the four transmitters;

(F) after the band amplifier, four signals being split into four paths by a splitter;

(G) band pass filters allowing only one frequency pass through each one of them;

(H) phase processor decoding the phase differences or the phase summations;

(I) phase calibration being done by either the software in computer, or by the phase calibrator before signal goes into computer;

(J) the same procedures being applied for the receiver of the second locator;

(K) computer receiving two groups of the phase messages for the positions of the two head locators ;

(L) computer processing the phase data by inverting the coordinates of the positions of the two receivers from the phase data;

(M) according to the coordinates of the two receivers, computer calculating the coordinates of each of the head in head array by using interpolation method;

(N) according to the position of each head, the computer searching the nearest pixel in the image data file to this position and taking the color data of this pixel, and sending the data to control unit;

(O) the control unit sending the action commands and power to head.

(P) head performing its job --- spraying or reading.

16. The phase-based method of claim 7, wherein an alternative means of directly suing RF comprising the same procedures as that in claim 15, except the following exceptions:

(A) transmitter and receiver are swapped;

(B) the four RF channels are combined together by a combiner, before being sent to the transmitting antenna;

(C) the four receiving antennas receive the signals and send the signals to four band-pass filters, which allow only one frequency to pass through each one of them;

(D) the four channels being then sent to phase processor after amplified.

17. The phase-based method of claim 7, wherein the means of using RF- modulation on carrier-wave comprising the following procedures of controlling and processing:

(A) single RF frequency ω being generated by the RF oscillator and is amplified;

(B) driver of RF carrier-wave providing four currents to four sources of carrier-wave to emit four radiation with four wavelengths or frequencies $\Omega_1, \Omega_2, \Omega_3, \Omega_4$;

(C) The RF splitter splitting the RF signal into four paths and sends the RF to each source of the carrier-waves so that the amplitude or frequency of carrier-wave is modulated by RF;

(D) four-detector receiver receiving radiation and converting the power into RF currents;

(E) each of the detectors having a different optical filer to allow only one of the four frequencies $\Omega_1, \Omega_2, \Omega_3, \Omega_4$ to pass through;

(F) The detected RF currents being sent to the four RF band pass filters with frequency ω;

(G) The phase differences of first two signals and the last two signals being recovered by two digital phase detector (DPD), and sent to computer after amplified;

(H) the two filters filtering out high frequency if the phase difference is used, or for filtering out the low frequency if the phase sum is used, in the case of phase detector is a using the mixer (instead of DPD);

(I) steps (K) to (P) in claim15 being applied for computer processing and control.

18. The phase-based method of claim 7, wherein an alternative means of using RF-modulation on carrier-wave comprising the same procedures as that in claim 17, except the following exceptions :

(A) four transmitters radiating two wavelengths instead of four wavelengths;

(B) each one of the two receivers filtering out a light frequency and detecting the two signals that is carried by the other frequency, and then sending the two detected RF signals to a RF band pass filter;

(C) the two signals in each of the two pairs being internally homodyned at a phase detector after the amplified;

(D) the output from the phase detector, after a low pass filter, is a sinusoid function of the phase difference, which is sent to computer.

19. The phase-based method of claim 7, wherein the alternative means of using RF-modulation on carrier-wave have the same procedures as that in claims 17 and 18, except the following differences:

(A) the transmitters and receivers are swapped;

(B) the four-light-source transmitter is installed on the head holder;

(C) four corner receivers are used at the corners

20. The time-based method of claim 8, wherein the means of controlling and processing comprising the following procedures, whereby the procedures are illustrated by (but not limited to) the ultrasonic pulse:

(A) pulse clock sends periodic commands for generating a pulse-modulated current with an ultrasonic frequency;

(B) the amplified current is sent to ultrasonic pulse transmitter;

(C) in the meantime, a signal is send out to start time-counting at the moment the ultrasonic wave is sent out;

(D) ultrasonic pulse is received by receivers, the signal is amplified and is sent to triggers to stop the time-counting;

(E) the time counters send the time differences to computer;

(F) the ultrasonic frequency filters are used to distinguish the two pulses from the two transmitters (locators).

21. The time-based method of claim 8, wherein an alternative means of controlling and processing comprising the same procedures as that in claims 20, except the following differences]:

(A) the transmitter and receiver are swapped;

(B) two (instead one) ultrasonic pulses with different frequencies are transmitted from two transmitters;

(C) the mixed signal from receiver after amplified is split into two paths by splitter;

(D) each of the two filters blocks out the other frequency and sends the pulse to triggers to stop the time-counting.

22. The means of claim 15, wherein the means of phase processor comprising the following procedures of controlling and processing :

(A) the first two frequencies and last two frequencies are conducted to two mixers respectively, which produce another two frequencies --- their sum and difference.

(B) two band pass filters filter out the sum frequencies and pass the difference frequencies, and two digital phase detectors (DPD) (or mixers) decodes the phase difference (or its sin( )) by homodyne;

(C) or (optional) two band pass filters filter out the difference frequencies and pass the sum frequencies, and two DPD (or mixers) decodes the phase sum (or its sin( )) by homodyne.

23. The phase-based method of claim 7, wherein the means of computer signal processing and positioning for one head locator, comprising the following means and procedures:

(A) CALIBRATION of system, INITIALIZING image status, determining calibration coefficient, and finding out scale transformation;

(B) determining the two distance differences (DD), by using the phase difference (PD) at (0,0) and the calibration coefficients.

24. The system of claim 1, wherein the computer processing, system operation and embodiment controlling for both phase-based case (linear and nonlinear phase dependencies, using phase difference and phase sum) and time-based case, and for one head locator, comprising the following COMMON means's and procedures:

(A) INVERTING THE LOCATOR'S POSITIONS by solving equations and by by Surface fitting ;

(B) taking all the stored image data and checking the status of each pixel ;

(C) if the pixel has been sprayed (P *(i) =1)*, the next pixel is checked;

(D) if all the pixels have been sprayed (all *P(i)=1*), the job is finished, and stop;

(E) if there is at least one pixel with status flag *P (i)=0*, then judge how close this pixel to the locator position (x, y);

(F) if the distance is less than or equal to the criteria, taking the color data of this pixel from the image file, and then sending the commands and spraying, meanwhile setting the status flag to 0 for this pixel;

(G) if the distance is greater than the criteria, then check the next pixel with status flag 0;

(H) if there is no such pixel that satisfies this condition at all, then program will wait for the next trigger for the next chance of meeting a pixel which is spray-able, during head causally moving;

(I) (optional) two fast-response micro-motors starting their work to slightly adjust the sprayer array position and direction for improving the efficiency if there is no such a pixel at all ;

whereby, for the case of linear phase dependence and using phase difference, the contour curves for constant phase differences are a class of hyperbola curves, for the case of linear phase dependence and using phase sum, the contour curves for constant phase sum are a class of ellipse curves.

25. The system of claim 1, wherein the computer processing, system operation and embodiment controlling, for the POSITIONING OF EACH INDIVIDUAL HEAD IN HEAD ARRAY, comprising means's and procedures :

(A) same procedures claimed in claims 24 are applied for each one of the two locator;

(B) determining the position coordinates of the two locators, based on the phase information from the two locators;

(C) using interpolation method to determine the position coordinates of each head along the head array;

(D) is the distance between a head and a pixel less than the criteria?

if yes --- at least one, the computer takes the color data from that pixel and sets status flag to 0, and then commands that sprayer to spray .

if no --- continue moving and waiting the next chance;

if no, or (optional) an alternate for improving the efficiency with three fast-response micro-motors to slightly adjust (move and rotate) the sprayer array position and direction, by taking in the account the moving trend and inertia.

26. The phase-based method of claim 7, wherein the means of PHASE-CURRENT PROCESSING comprising the following procedures:

(A) the phase shifters is so adjusted that DPD or mixer has zero output when the difference of inputted phases is zero;

(B) for higher resolution applications, the current-phase wrapping is specially treated by assigning and recognizing region ID number of locator position status;

(C) before head starts moving at center region, the computer initializes the ID number of the center region to locator position status;

(D) computer promptly changes the ID number when locator is across the region boundary, and the phase-current should jump a value from the detected-phase-current;

(E) for using mixer, detected-phase is determined by inverting the sine function from the detected–phase-current.

Whereby, using a very large number of phase wrapping is corresponding to a relative-motion-based method

27. The time-based-method of claim 8, wherein the computer processing comprising the following procedures:

(A) computer receives two time differences, t_{A1} and t_{A2} from the OU;

(B) computer solves the root pairs (x, y) from the equations of distances;

(C) excluding the extraneous Roots.

28. The relative-motion-based method of claim 9, wherein the computer processing for optical image-motion detector based approach comprising the following means's and procedures:

(A) initial setting of the reference point of the relative motion a;

(B) hereafter, for every trigger moment, picture is taken for image-correlation;

(C) the picture-taken frequency is high enough, the position just changes a distance of a few pixels, even if with the fastest moving. Especially, if the head starts from steady state, the position just changes a distance within one pixel;

(D) image-correlation is defined as (but not limited to) the averaged summation of squares of difference (or absolute value of difference);

(E) locator positioning method for the cases: head speed-up motion and the head simple motion ;

(F) locator positioning method for head complex motion;

whereby, if a jump happens to the head carrier during the its moving on the image surface for some reason, the head needs to be put back to the center point of the image area for initially resetting the reference point for the relative displacement.

29. The computer processing of claim 28(E), wherein the positioning method for SIMPLE MOTION and SPEED UP MOTION comprising the following means and procedures:

(A) define surface-fitting center for present moment;

(B) use five-point image correlation method for the first maximization at surface-fitting center at each trigged moment and find out the maximum point on the surface, which is the actual position at the present moment;

(C) six-point image correlation method for the second maximization if needed or when maximum point from five-point fitting surface is outside of the frame;

whereby, the "frame" represents the quadrilateral frame, of which the four corners are at the four outer points with the center at the surface-fitting center, for five point fitting, or represents the pentagonal frame, of which the five corners are at the five outer points with the center at the surface-fitting center, for six point fitting.

30. The computer processing of claim 28(F), wherein the positioning method for COMPLEX HEAD MOTION has the following means and procedures:

(A) five-point image correlation method for the first maximization , and six-point image correlation method for the second-and-after maximization ;

(B) when the actual position of the picture is out of the frame , computer needs RE-SETTING SURFACE-FITTING CENTER;

(C) computer will fully use the old data for saving processing time if any old point is nearby or just at any one of the corners of frame with the new surface-fitting center.

31. The Doppler effect method of claim 10, wherein the means for computer signal processing and positioning comprising the following procedures:

(A) Doppler frequencies are detected while receiver is moving around in the two wave fields;

(B) the two velocities and then displacements of the head facing the two wave sources are inverted from the two Doppler frequencies, respectively;

(C) then the total displacement of the head and the head positions relative to the two sources at the moment of present trigger is determined;

(D) and then the root pair for coordinates of head is obtained.

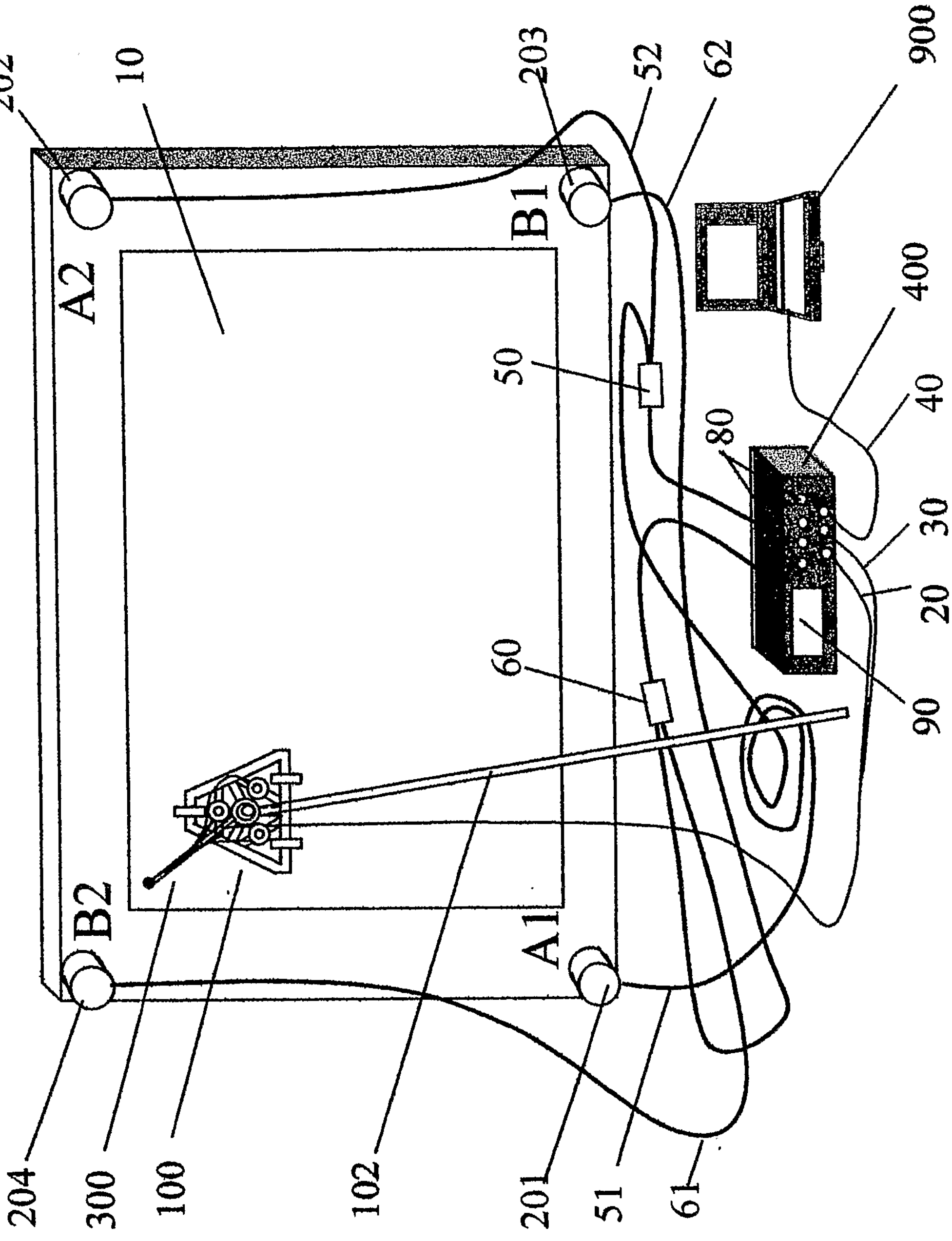

202
10
203
52
62
900
A2
B1
50
400
40
80
30
20
60
90
B2
A1
204
300
100
102
201
51
61

Fig. 1

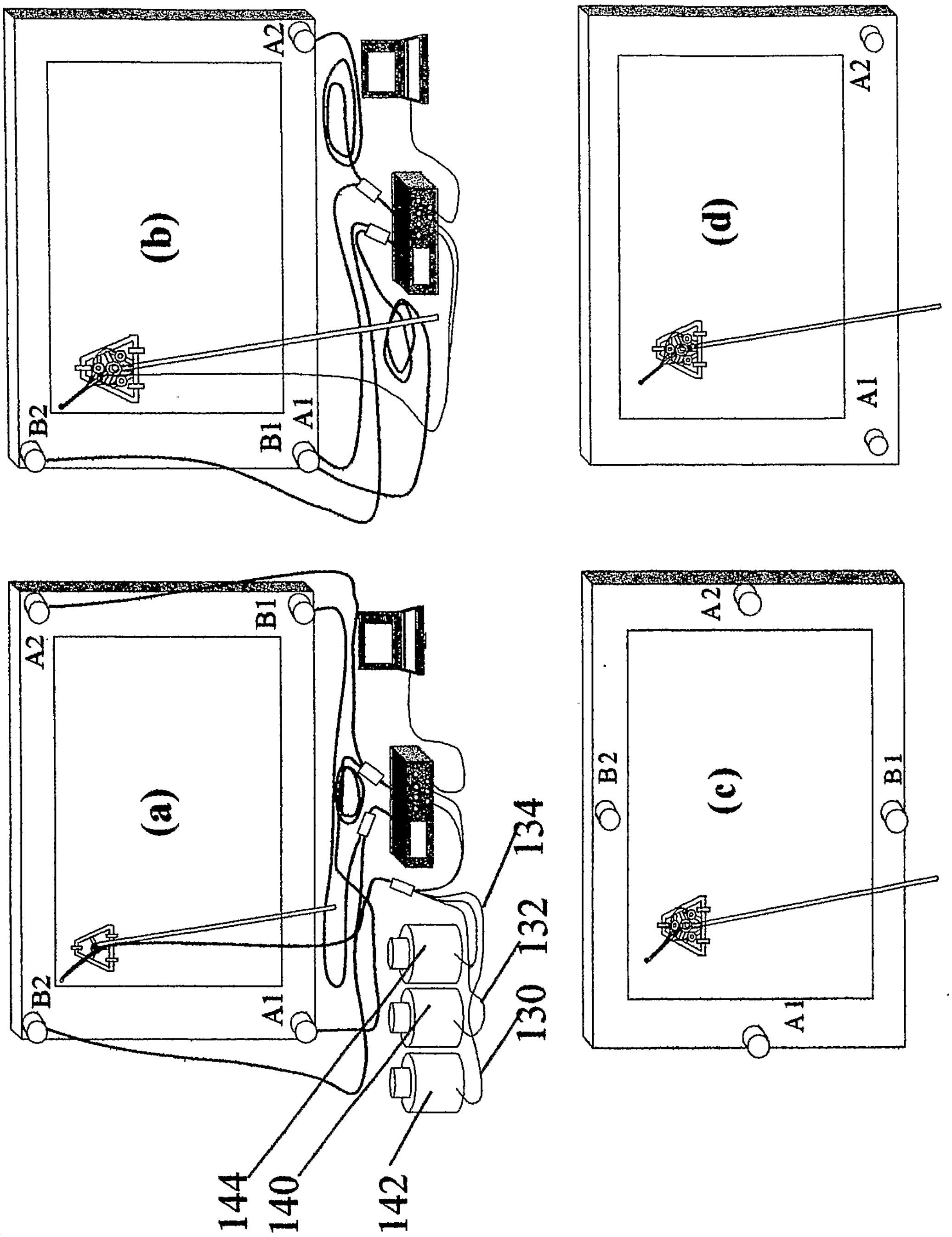


Fig. 2

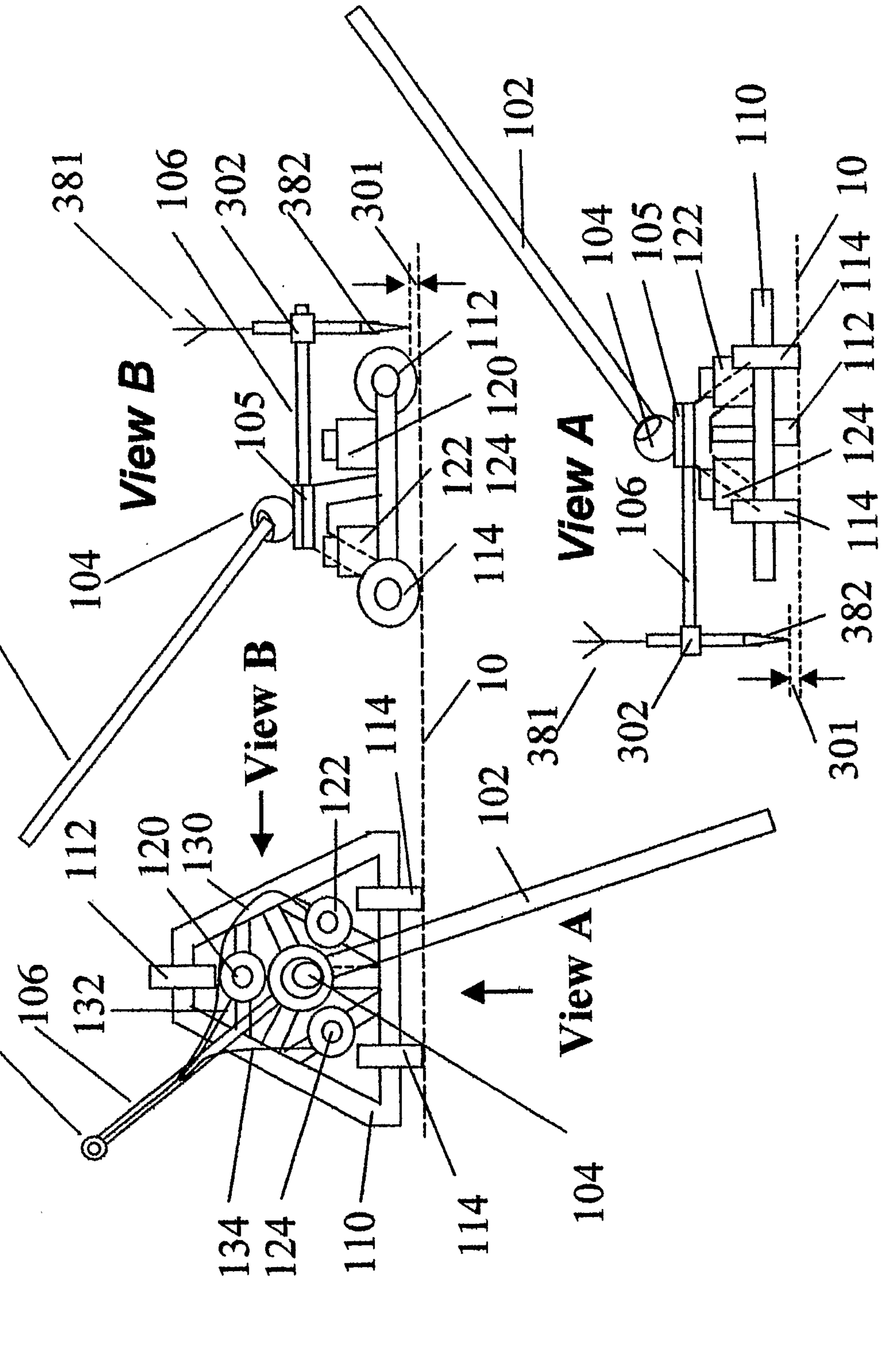

View A
View B
View A
View B
102
102
102
104
104
104
105
105
106
106
106
110
110
112
112
112
114
114
114
114
114
120
120
122
122
122
124
124
124
130
132
134
300
301
301
302
302
381
381
382
382
10
10

Fig. 3

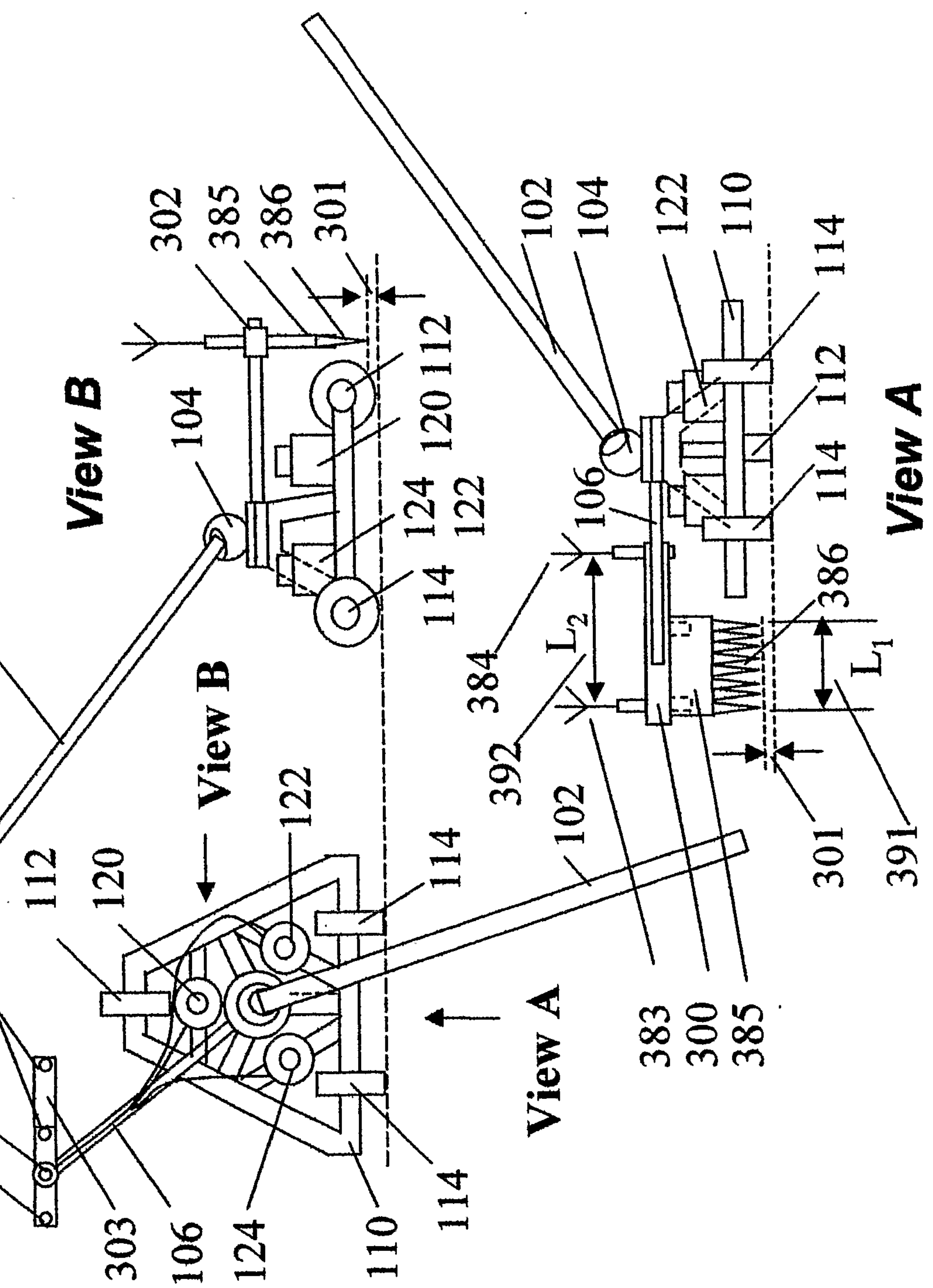

View A
View B
102
104
106
110
112
114
120
122
124
300
301
302
303
383
384
385
386
391
392
L2
L1

Fig. 4

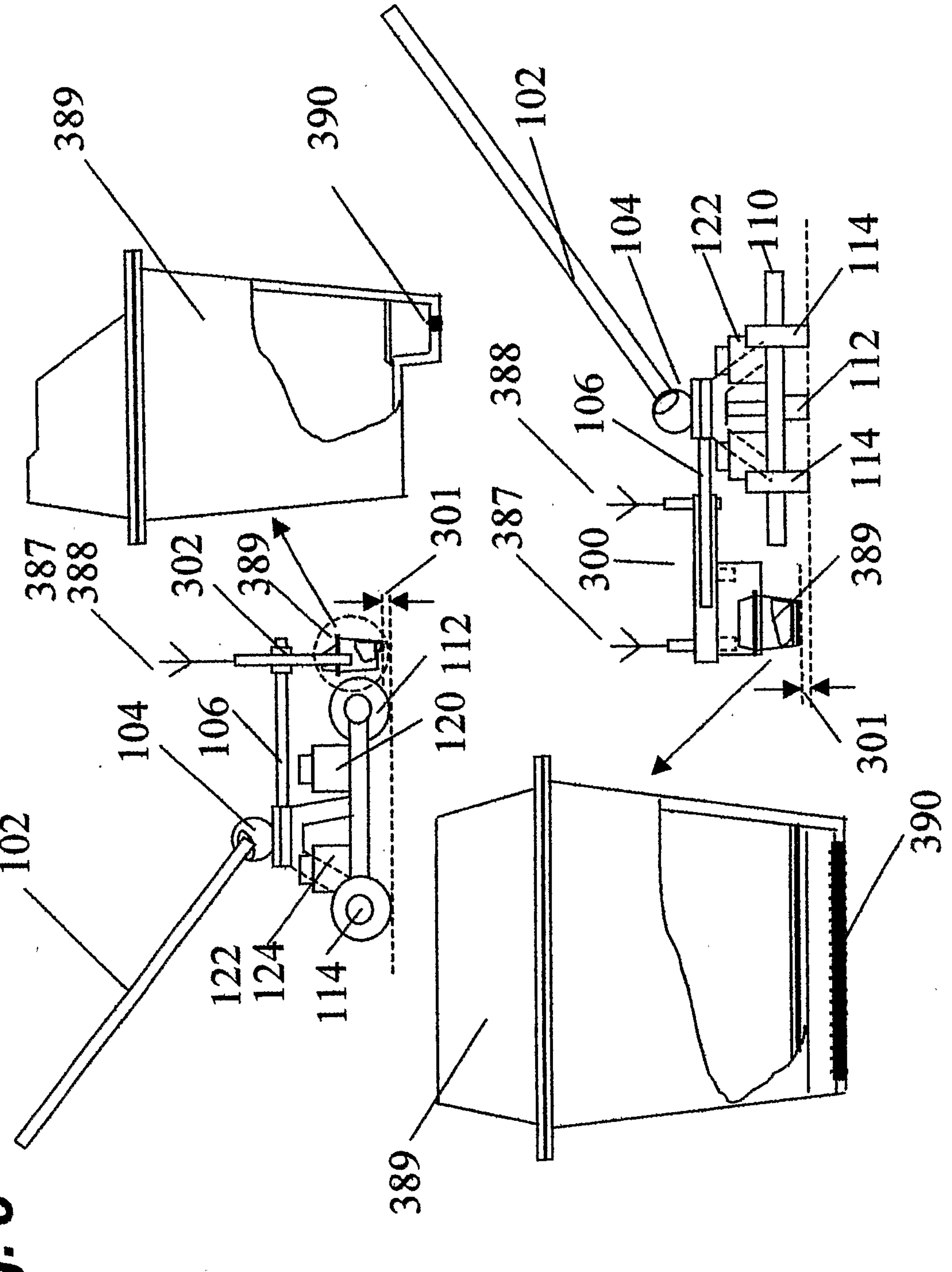

389
390
102
104
122
110
114
388
106
112
114
387
388
302
389
301
387
300
389
104
106
112
120
301
102
122
124
114
390
389

Fig. 5

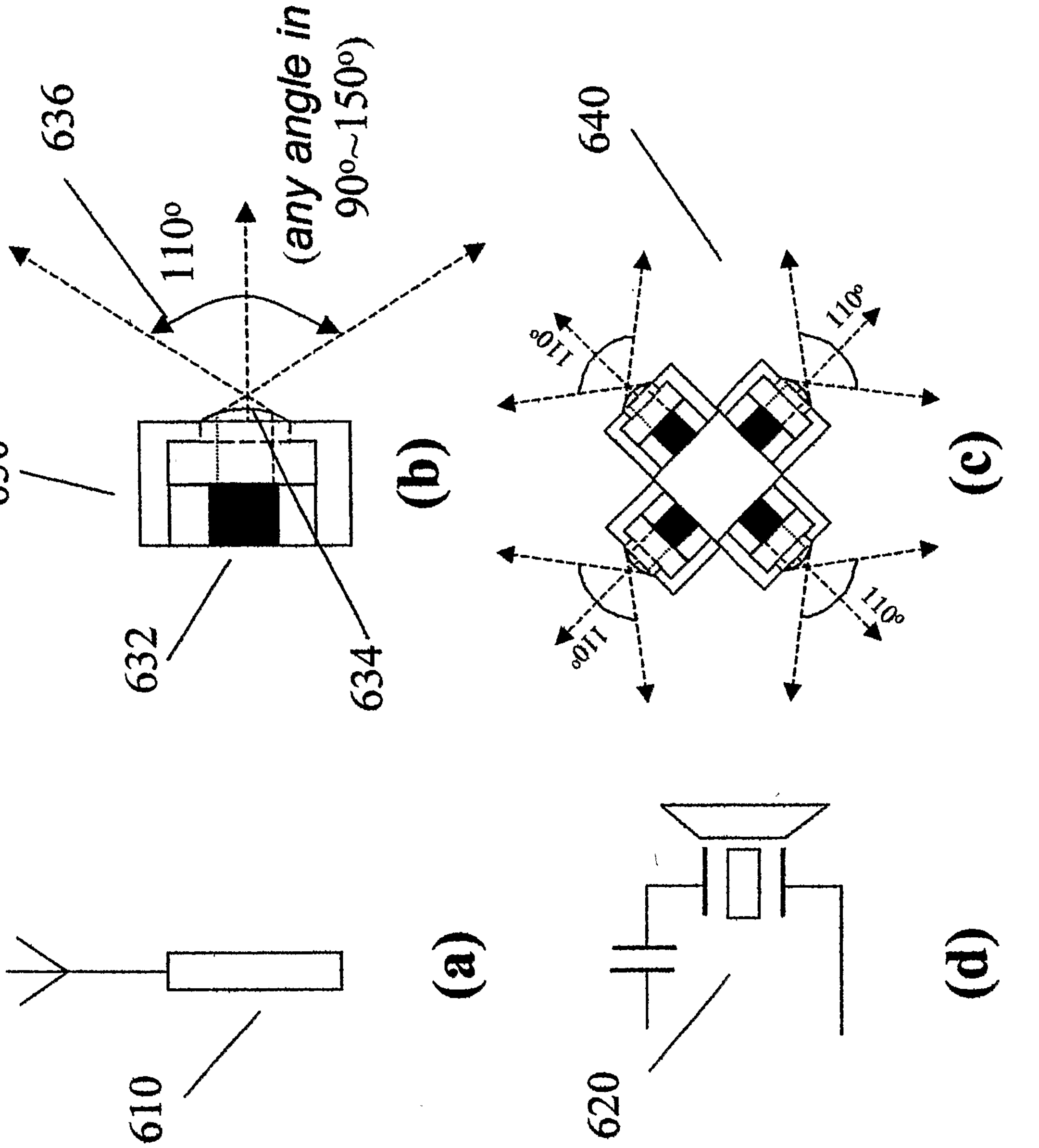

636
(any angle in 90°~150°)
110°
630
632
634
(b)
640
110°
110°
110°
110°
(c)
610
(a)
620
(d)

Fig. 6

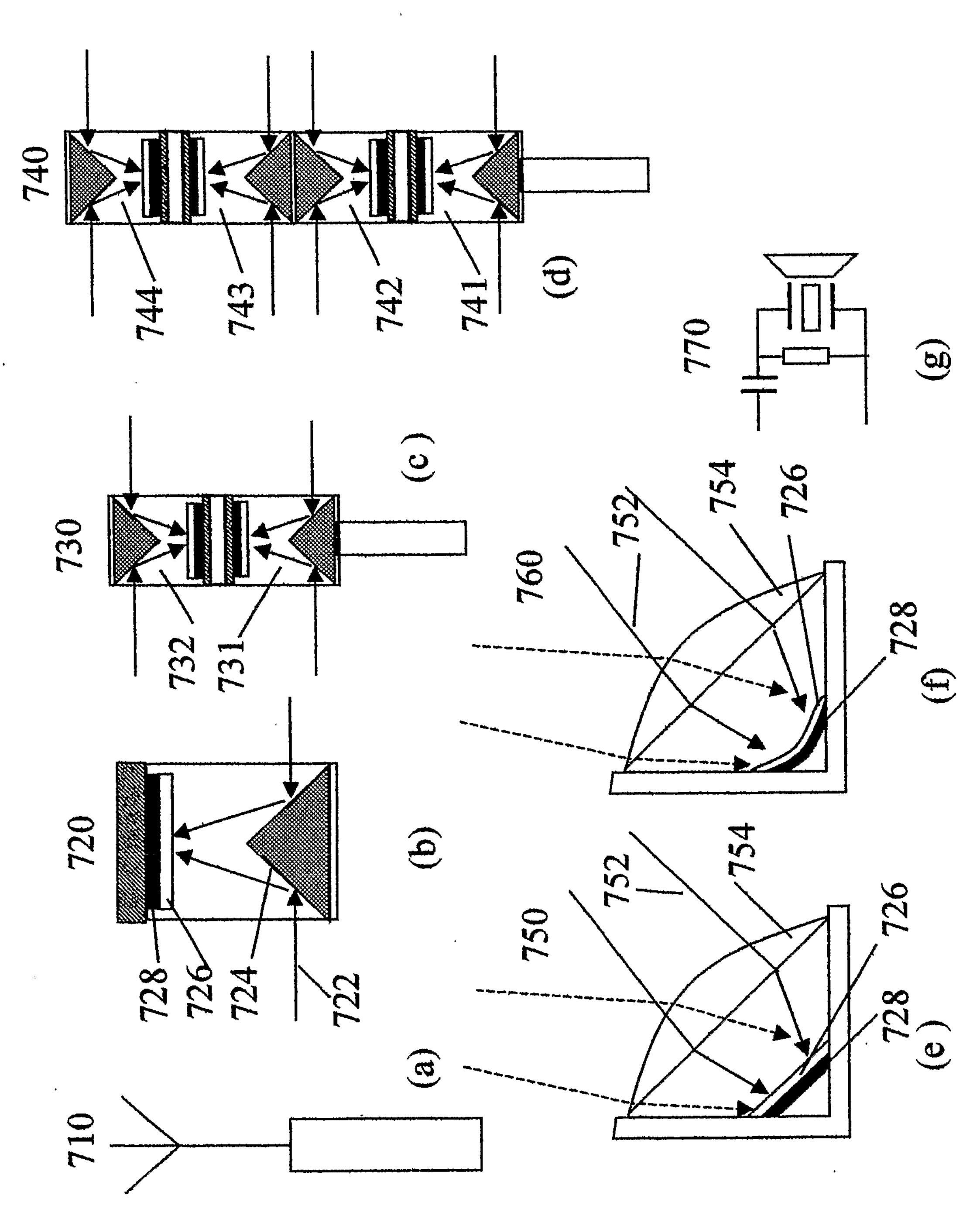

710
720
722
724
726
728
(a)
(b)
730
731
732
(c)
740
741
742
743
744
(d)
750
752
754
726
728
(e)
760
752
754
726
728
(f)
770
(g)

Fig. 7

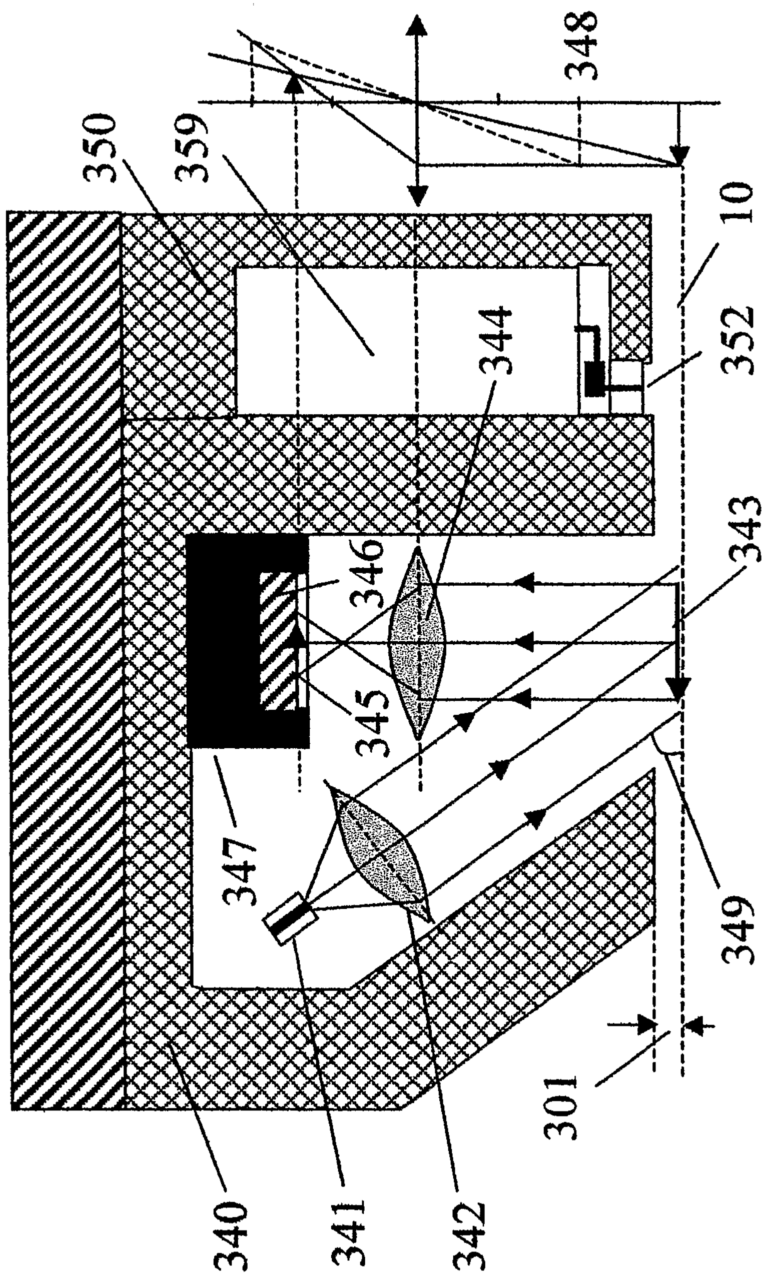


Fig. 8

Fig. 9

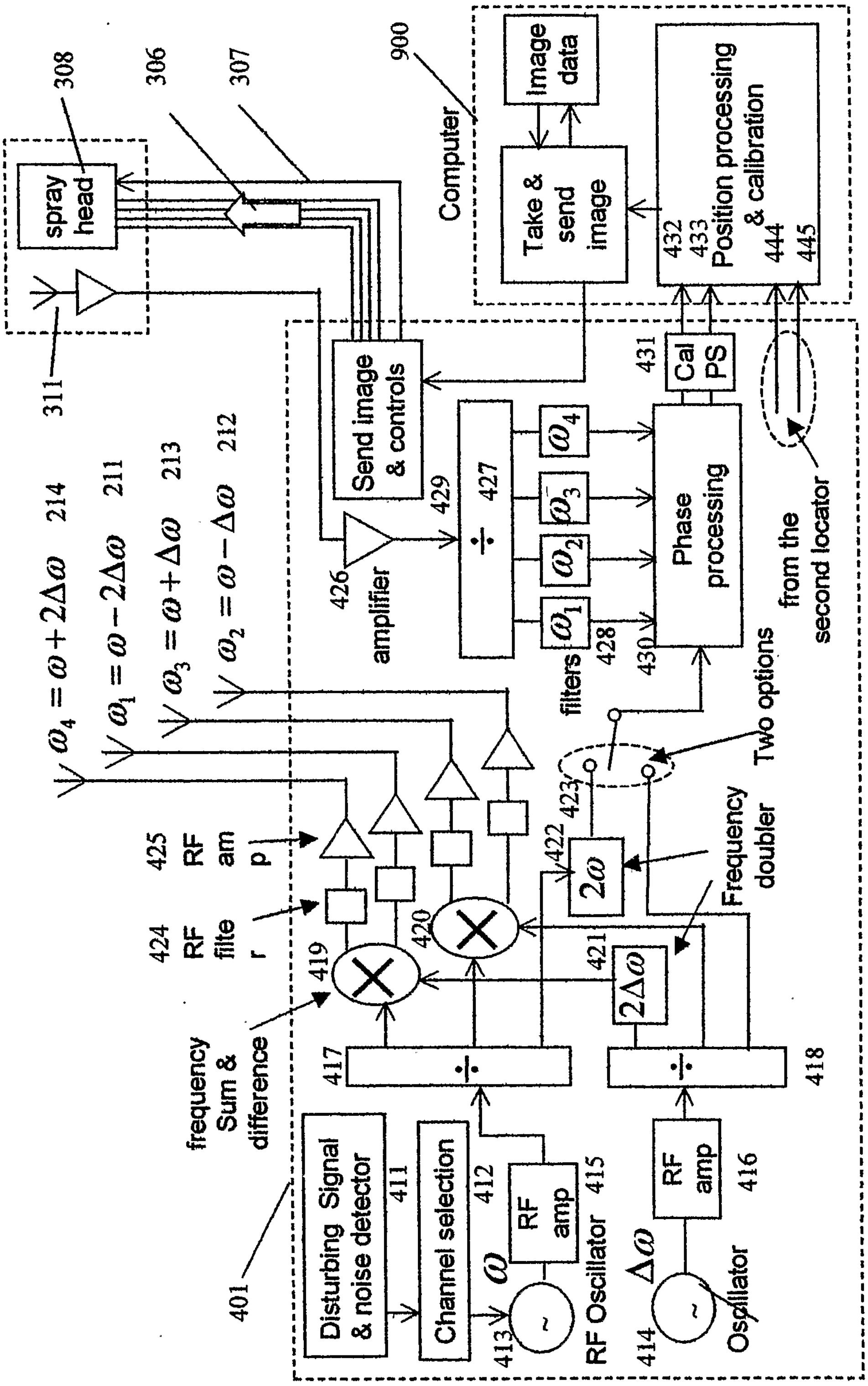

spray head
308
306
307
311
900
Computer
Image data
Take & send image
Position processing & calibration
432
433
444
445
$\omega_4 = \omega + 2\Delta\omega$ 214
$\omega_1 = \omega - 2\Delta\omega$ 211
$\omega_3 = \omega + \Delta\omega$ 213
$\omega_2 = \omega - \Delta\omega$ 212
Send image & controls
amplifier
426
429
427
431
Cal
PS
filters
428
430
Phase processing
from the second locator
Two options
423
422
Frequency doubler
2ω
$2\Delta\omega$
421
420
419
425 RF amp
424 RF filter
frequency Sum & difference
417
418
401
Disturbing Signal & noise detector
411
Channel selection
412
RF amp
415
ω
413
RF Oscillator
$\Delta\omega$
414
Oscillator
RF amp
416

Fig. 10

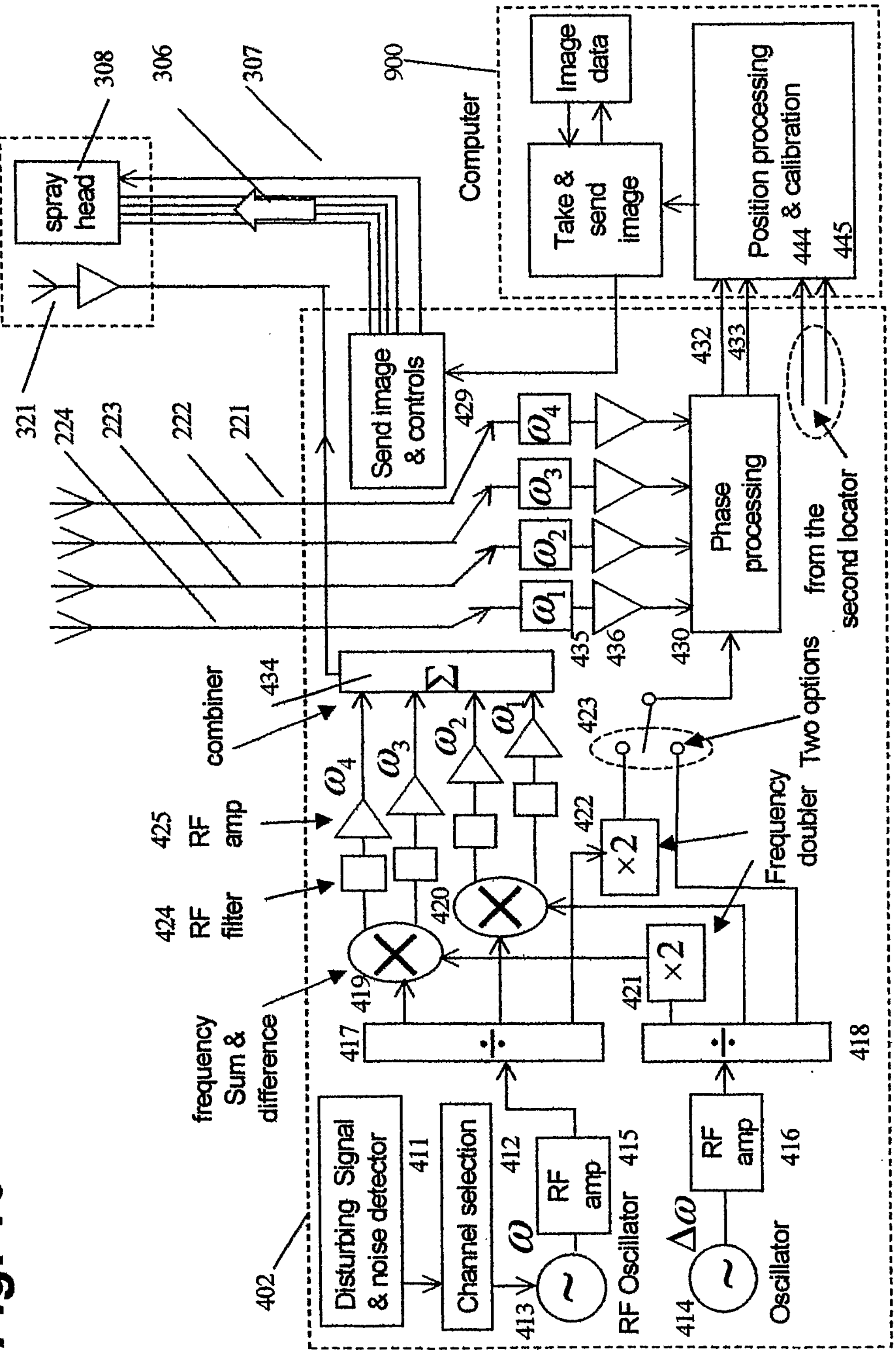

spray head
308
306
307
900
Computer
Image data
Take & send image
Position processing & calibration
444
445
321
224
223
222
221
Send image & controls
429
432
433
Phase processing
from the second locator
430
435
436
combiner
434
Σ
423
Two options
Frequency doubler
422
×2
425 RF amp
424 RF filter
420
419
421
frequency Sum & difference
417
418
402
Disturbing Signal & noise detector
411
Channel selection
412
RF amp
415
RF Oscillator
413
RF amp
416
Oscillator
414

Fig. 11

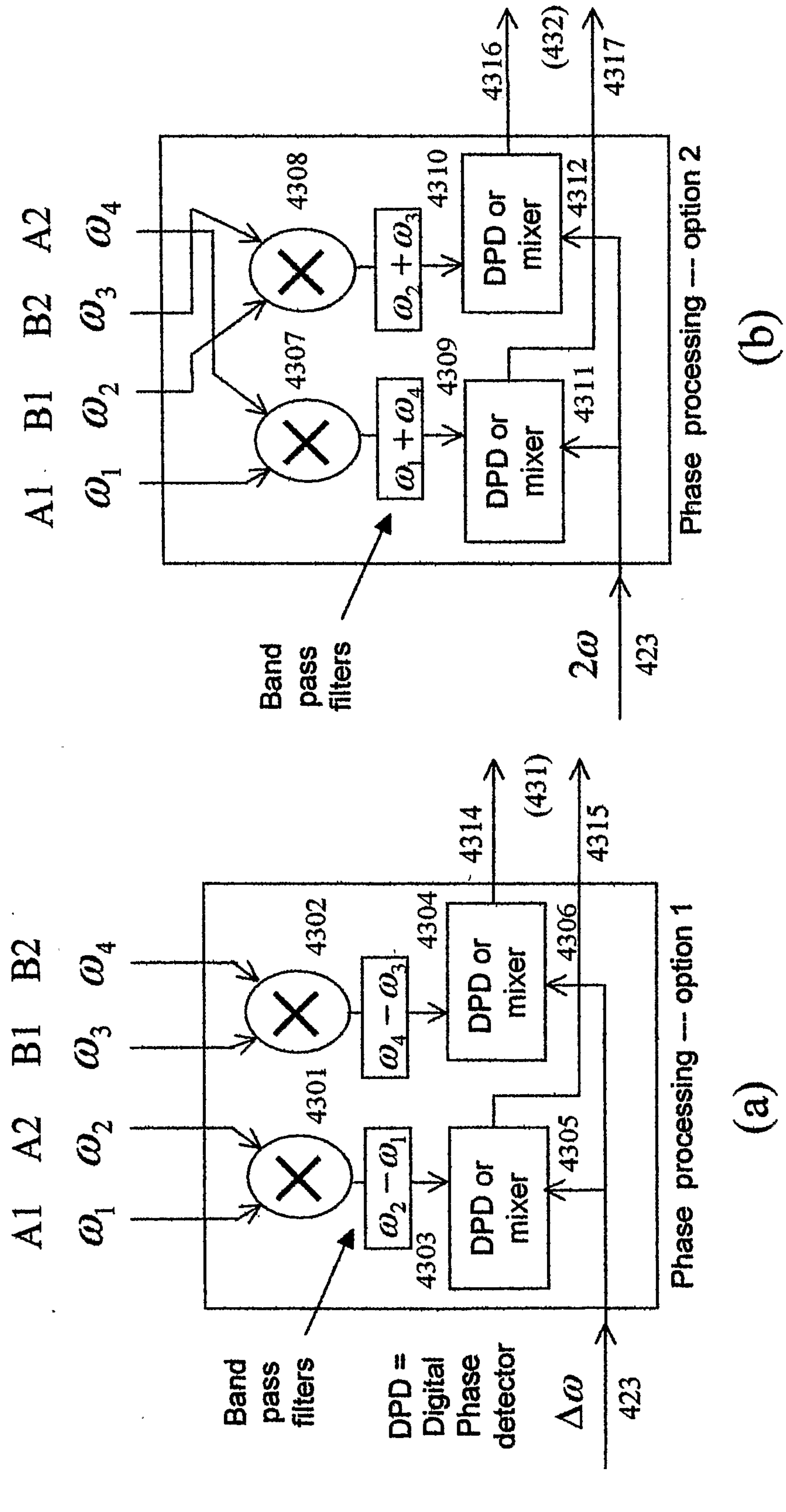

A1 A2 B1 B2
ω_1 ω_2 ω_3 ω_4
4301
4302
$\omega_2 - \omega_1$
$\omega_4 - \omega_3$
4303
4304
DPD or mixer
DPD or mixer
4305
4306
4314
(431)
4315
Band pass filters
DPD = Digital Phase detector
$\Delta\omega$
423
Phase processing --- option 1
(a)
A1 B1 B2 A2
ω_1 ω_2 ω_3 ω_4
4307
4308
$\omega_1 + \omega_4$
$\omega_2 + \omega_3$
4309
4310
DPD or mixer
DPD or mixer
4311
4312
4316
(432)
4317
Band pass filters
2ω
423
Phase processing --- option 2
(b)

Fig. 12

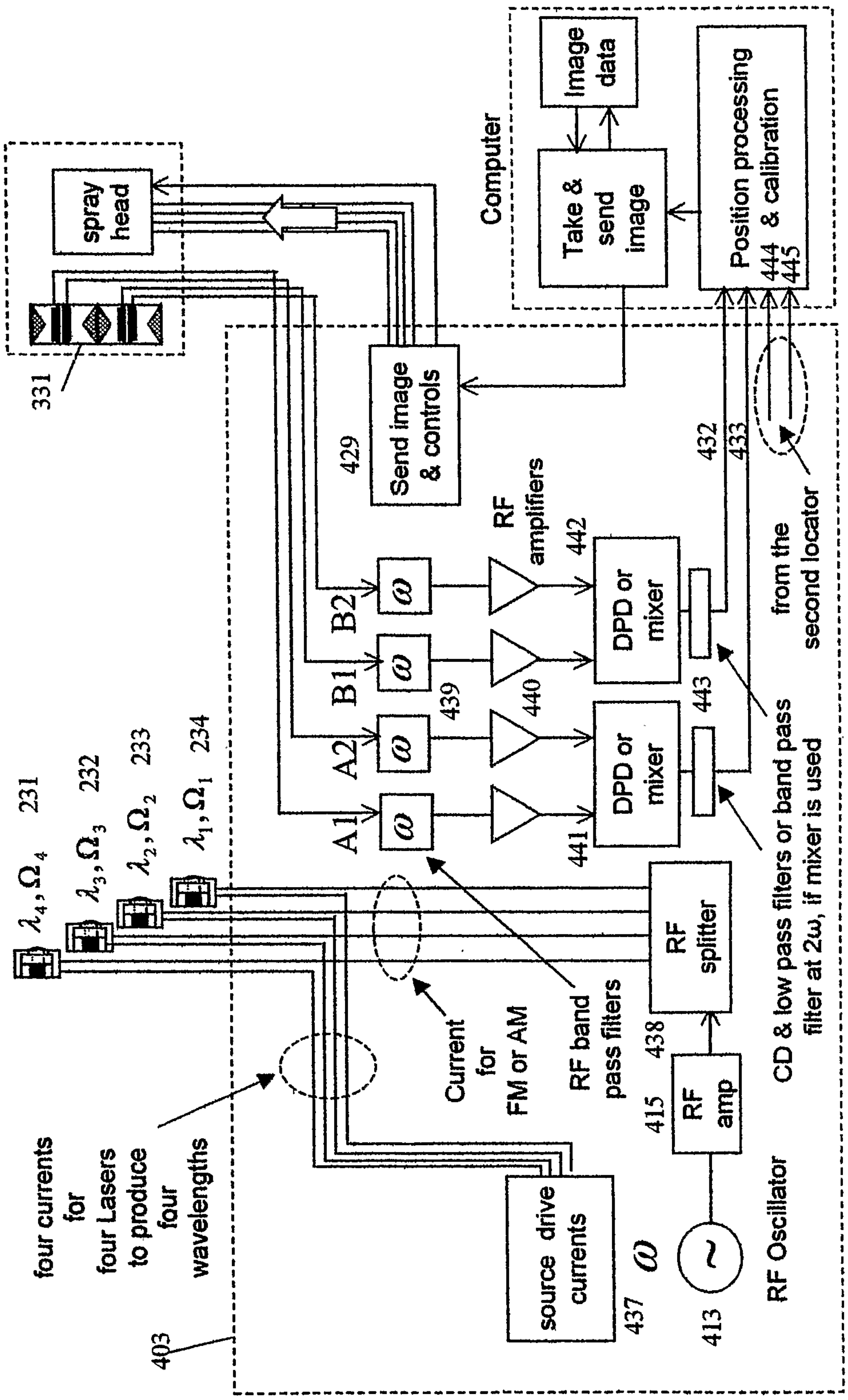

four currents for four Lasers to produce four wavelengths
403
source drive currents
437
ω
413
RF Oscillator
415
RF amp
438
RF splitter
Current for FM or AM
RF band pass filters
CD & low pass filters or band pass filter at 2ω, if mixer is used
λ_4, Ω_4
231
λ_3, Ω_3
232
λ_2, Ω_2
233
λ_1, Ω_1
234
A1
A2
B1
B2
439
440
441
442
443
RF amplifiers
DPD or mixer
DPD or mixer
from the second locator
432
433
429
Send image & controls
331
spray head
Computer
Take & send image
Image data
Position processing & calibration
444
445

Fig. 13

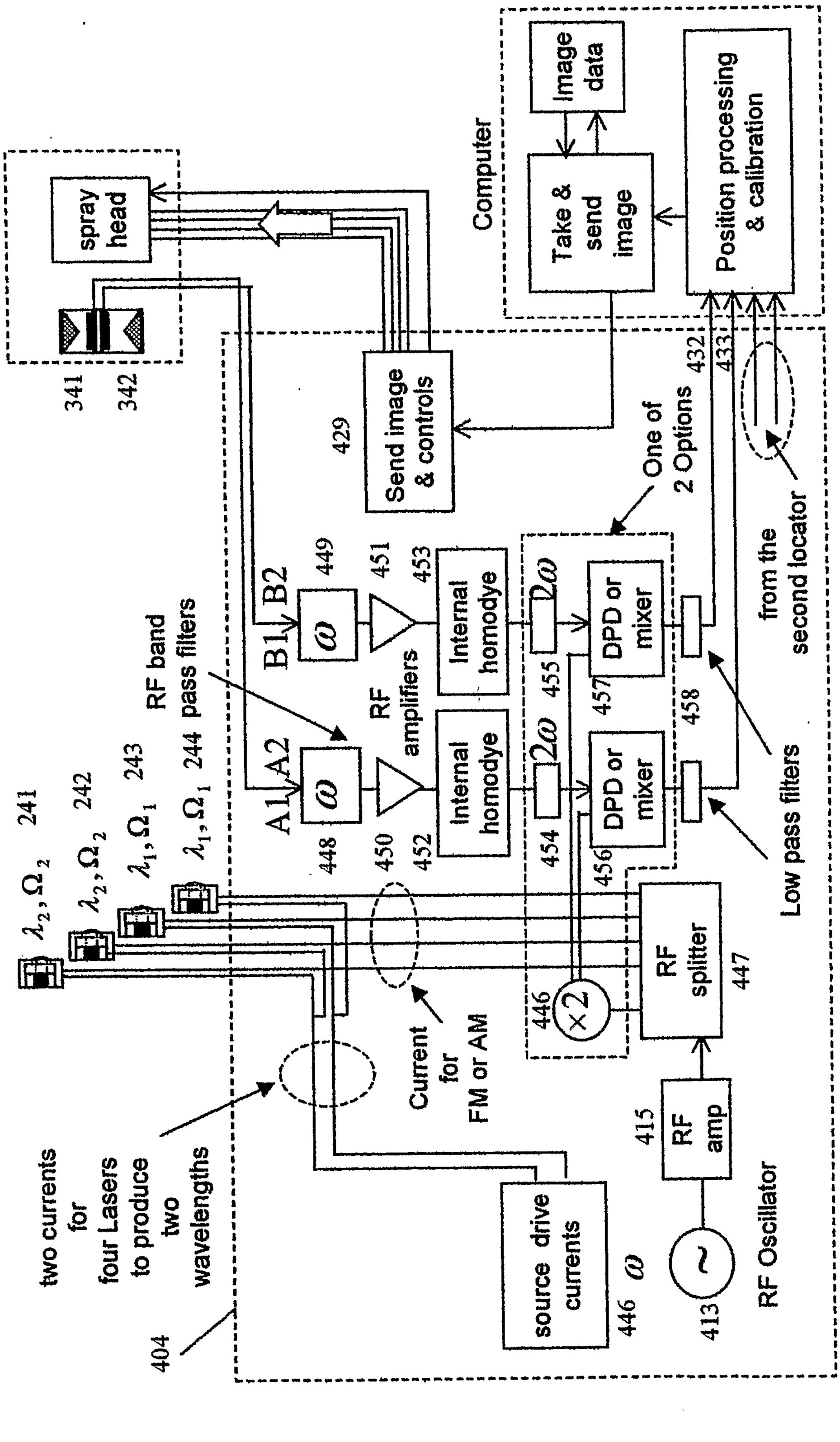

spray head
341
342
Computer
Image data
Take & send image
Position processing & calibration
Send image & controls
429
432
433
One of 2 Options
from the second locator
Low pass filters
458
DPD or mixer
DPD or mixer
457
456
455
454
2ω
2ω
Internal homodye
Internal homodye
453
452
RF amplifiers
451
450
ω
ω
449
448
B1 B2
A1 A2
RF band pass filters
241
242
243
244
λ_2, Ω_2
λ_2, Ω_2
λ_1, Ω_1
λ_1, Ω_1
Current for FM or AM
RF splitter
447
446
×2
RF amp
415
RF Oscillator
413
source drive currents
446 ω
two currents for four Lasers to produce two wavelengths
404

Fig. 14

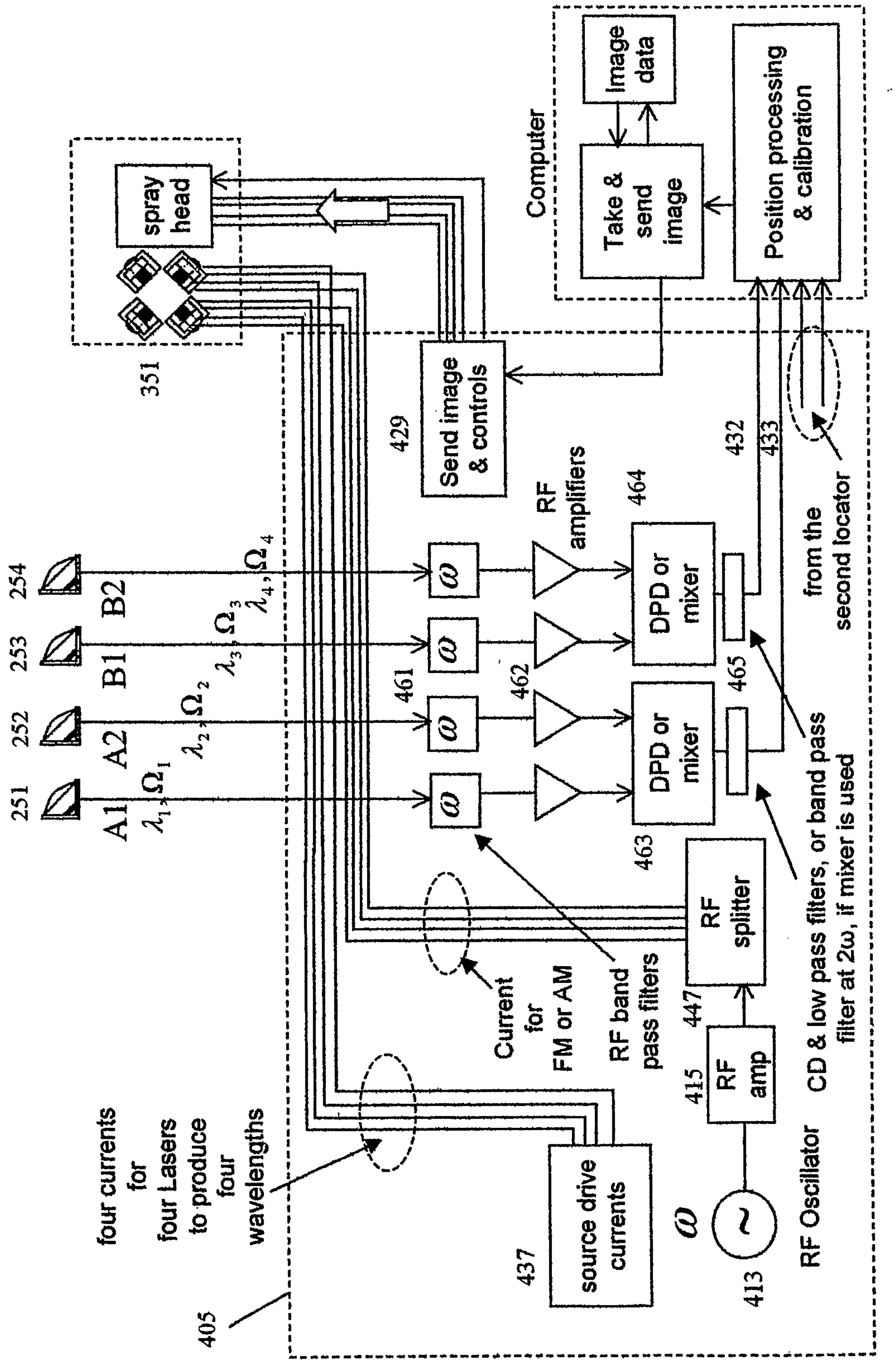

spray head
351
Computer
Image data
Take & send image
Position processing & calibration
429
Send image & controls
A1 λ_1, Ω_1
A2 λ_2, Ω_2
B1 λ_3, Ω_3
B2 λ_4, Ω_4
251
252
253
254
461
462
463
464
465
RF amplifiers
DPD or mixer
DPD or mixer
432
433
from the second locator
CD & low pass filters, or band pass filter at 2ω, if mixer is used
RF splitter
Current for FM or AM
RF band pass filters
447
415
RF amp
RF Oscillator
413
ω
source drive currents
437
four currents for four Lasers to produce four wavelengths
405

Fig. 15

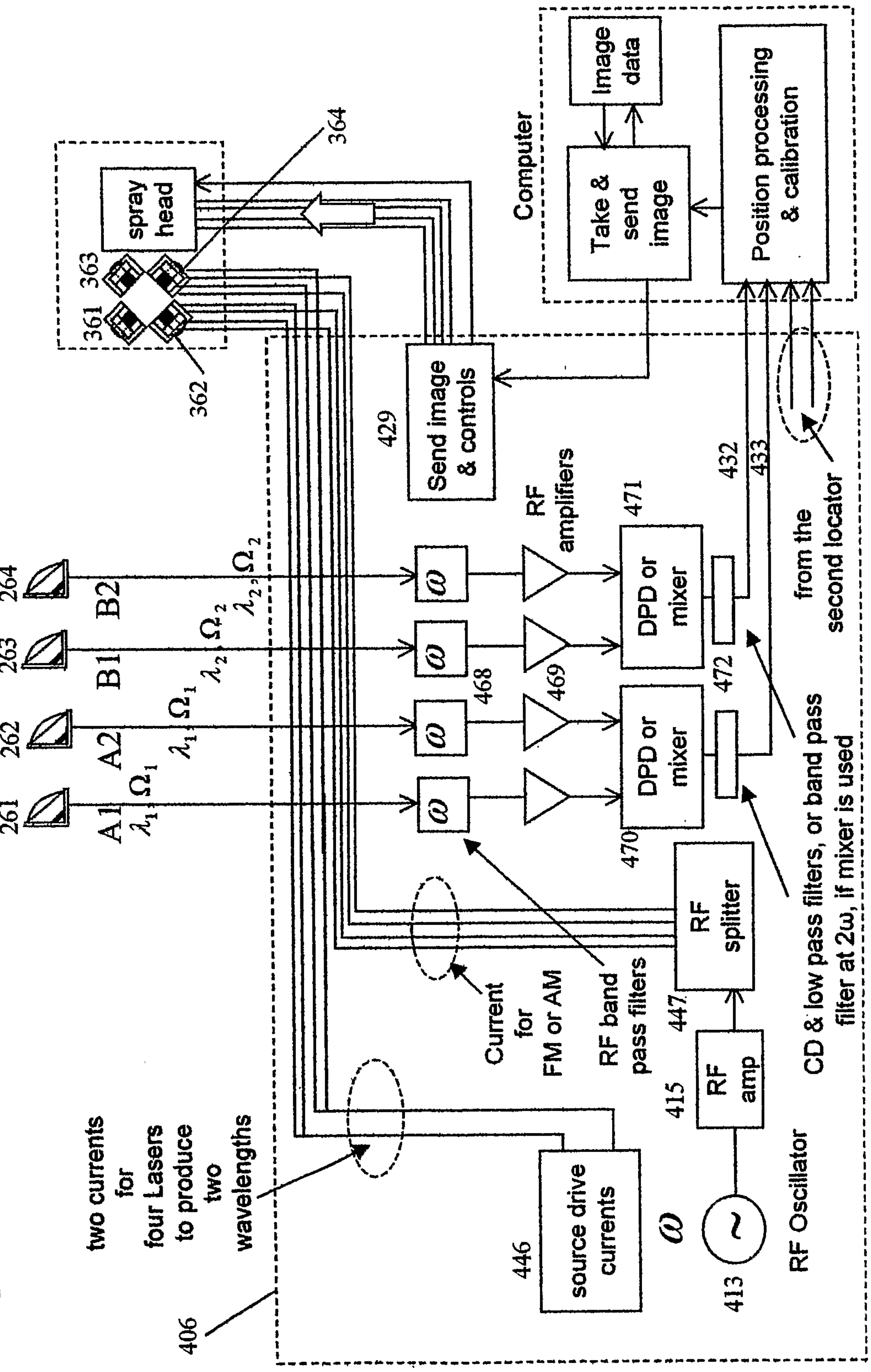

two currents for four Lasers to produce two wavelengths
406
446
source drive currents
ω
413
RF Oscillator
415
RF amp
447
RF splitter
Current for FM or AM
RF band pass filters
CD & low pass filters, or band pass filter at 2ω, if mixer is used
261
262
263
264
A1
A2
B1
B2
λ_1, Ω_1
λ_1, Ω_1
λ_2, Ω_2
λ_2, Ω_2
468
469
470
471
472
RF amplifiers
DPD or mixer
DPD or mixer
from the second locator
432
433
429
Send image & controls
361
362
363
364
spray head
Computer
Take & send image
Image data
Position processing & calibration

Fig. 16

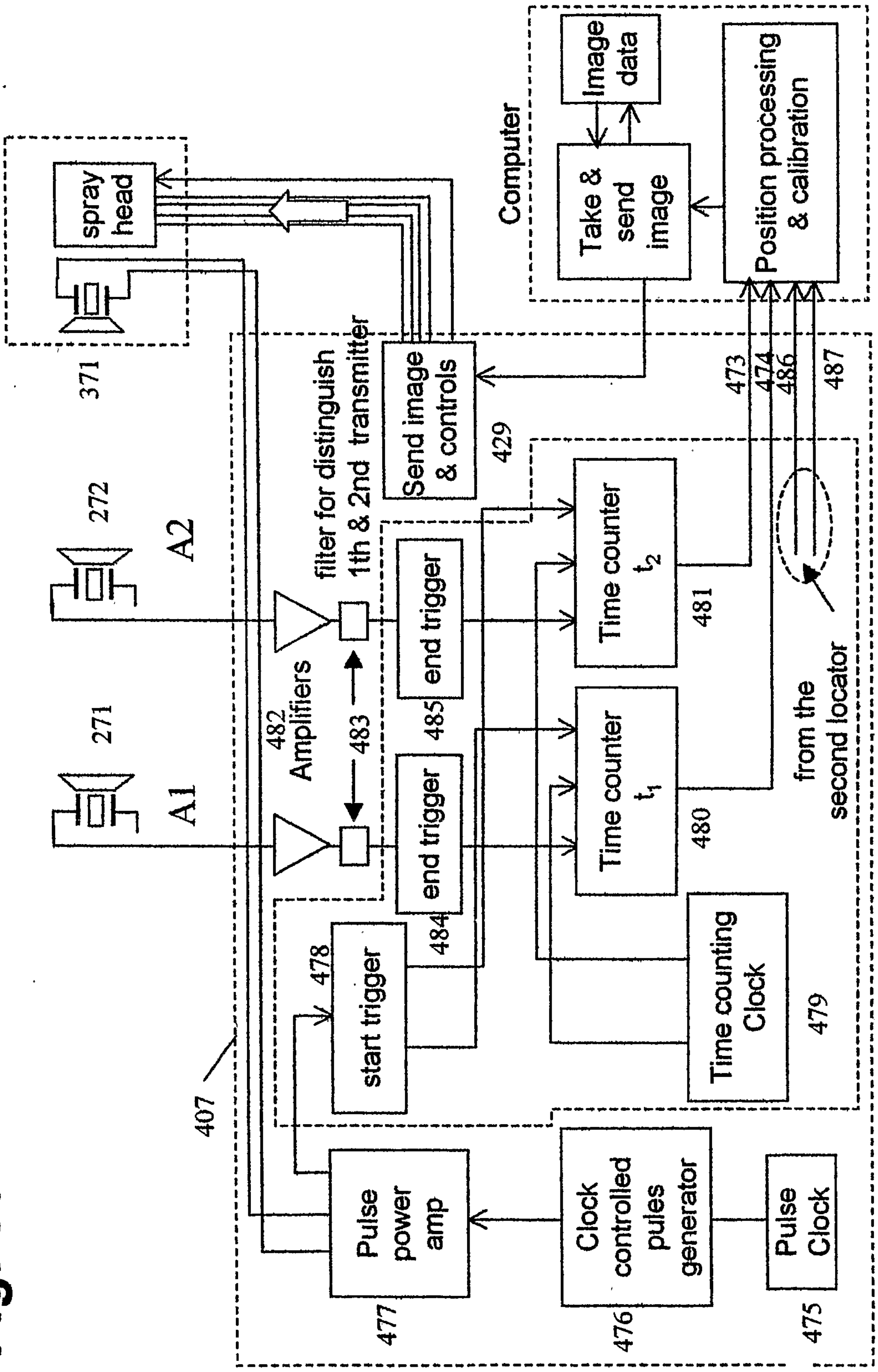
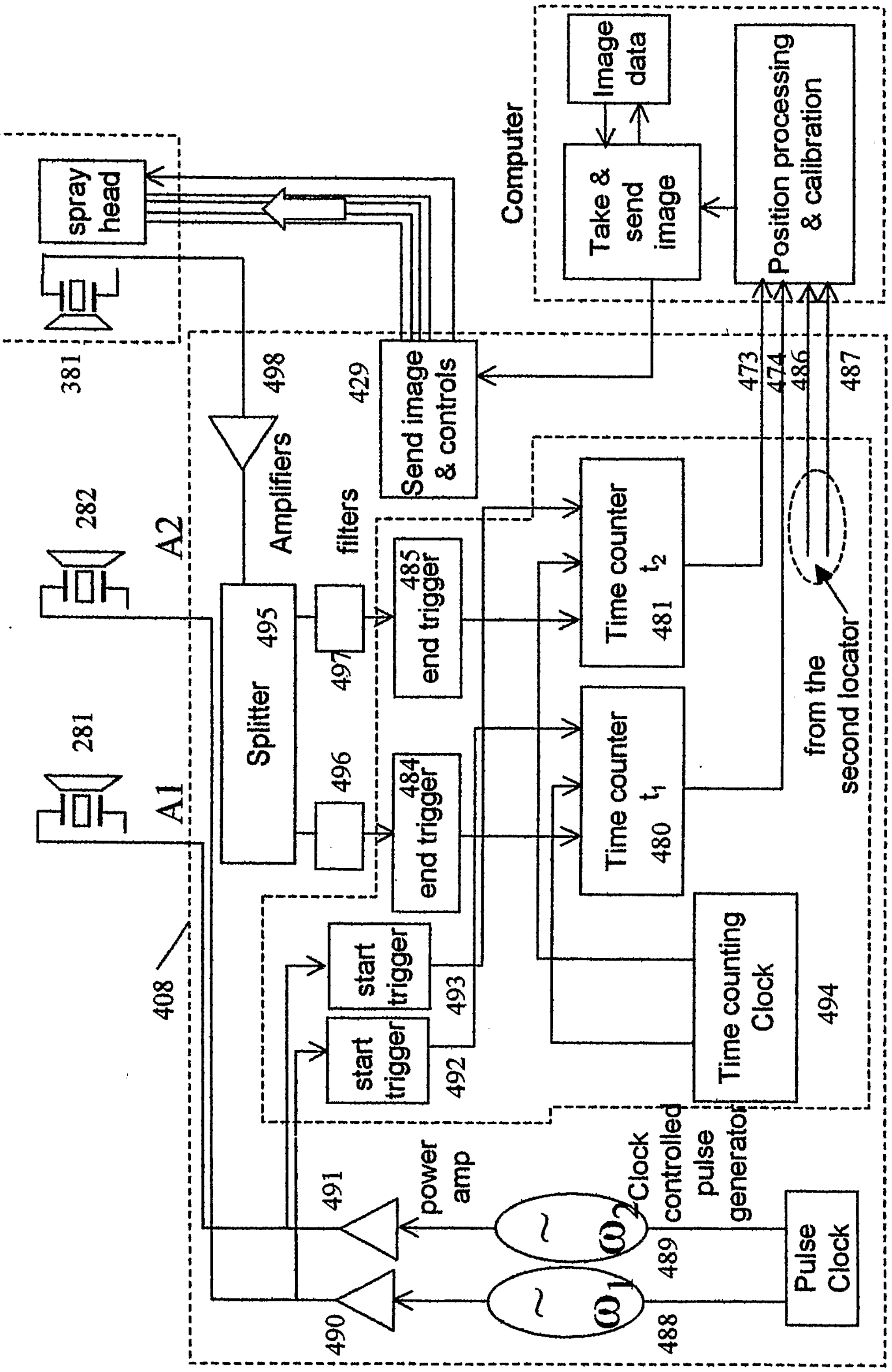
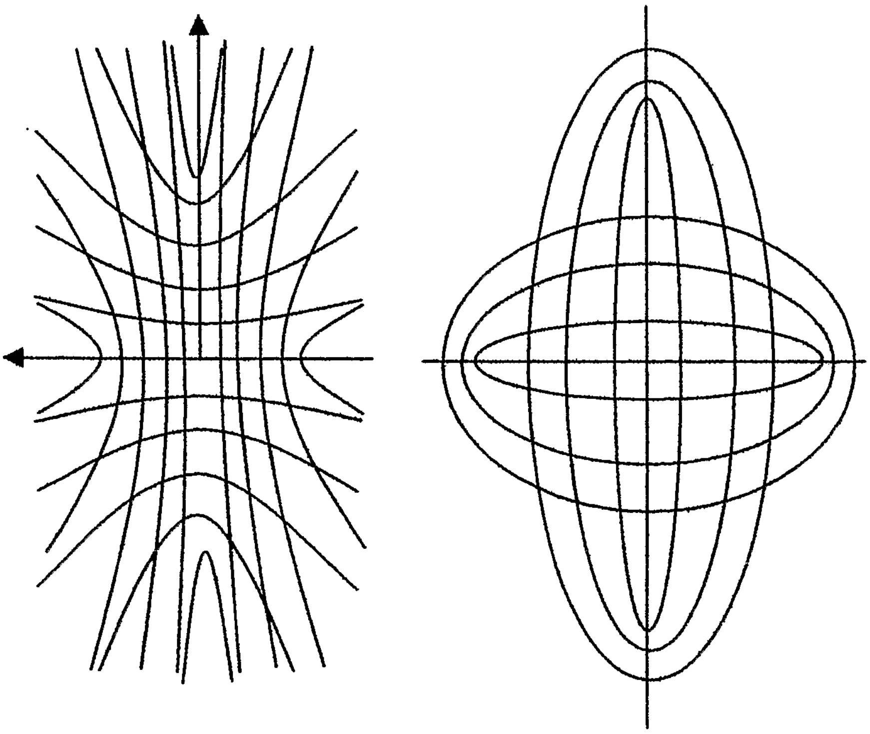

spray head
371
272
271
A1
A2
Amplifiers
482
483
filter for distinguish 1th & 2nd transmitter
Send image & controls
429
Computer
Take & send image
Image data
Position processing & calibration
473
474
486
487
end trigger
485
end trigger
484
start trigger
478
Time counter t_2
481
Time counter t_1
480
Time counting Clock
479
from the second locator
407
Pulse power amp
477
Clock controlled pules generator
476
Pulse Clock
475

Fig. 17


spray head
381
Computer
Image data
Take & send image
Position processing & calibration
Send image & controls
429
498
Amplifiers
filters
282
281
A2
A1
Splitter
495
497
496
485 end trigger
484 end trigger
Time counter t_2
481
Time counter t_1
480
473
474
486
487
from the second locator
start trigger
start trigger
493
492
Time counting Clock
494
408
491
490
power amp
Clock controlled pulse generator
ω_2
ω_1
489
488
Pulse Clock

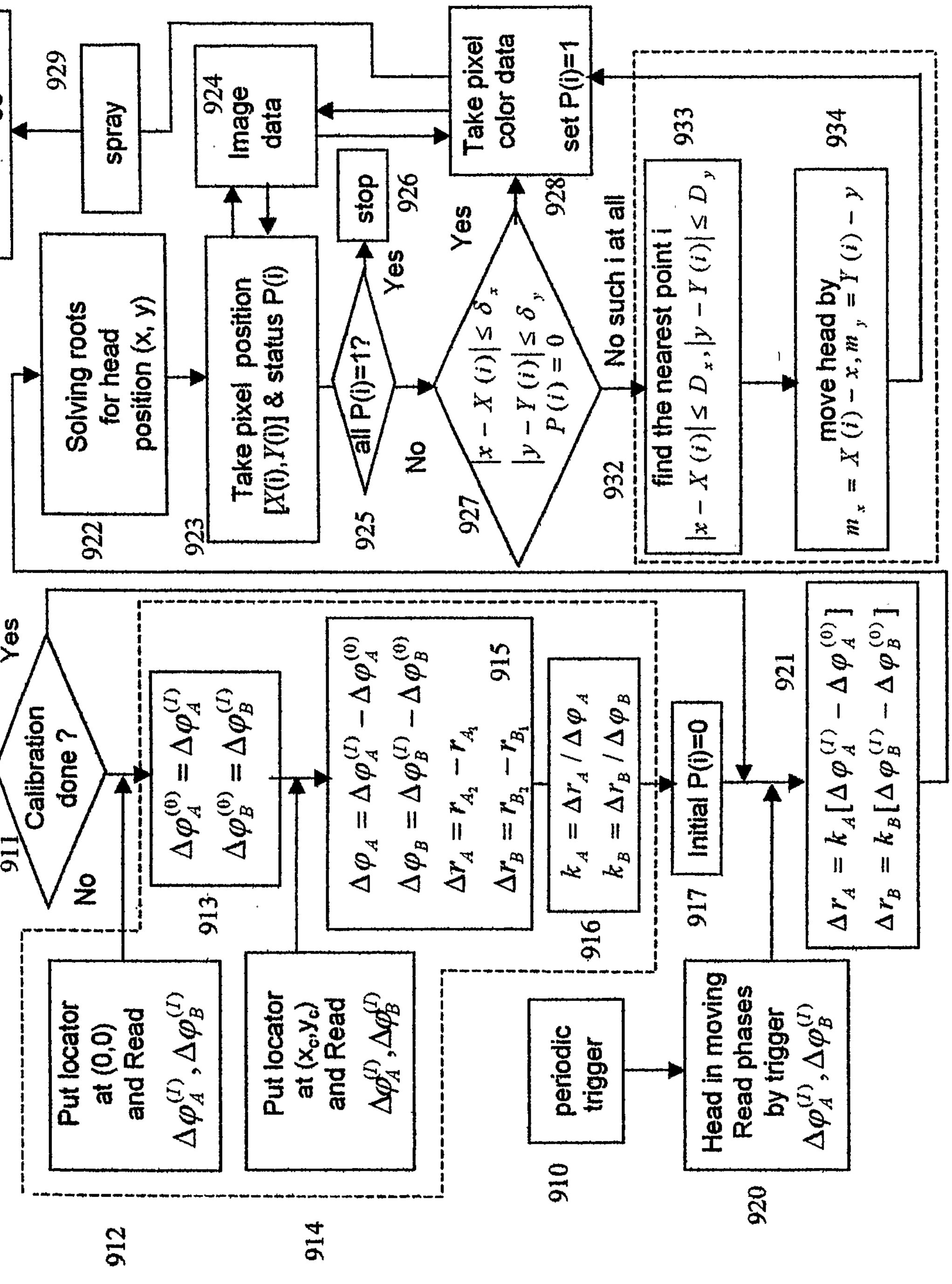


(a)

(b)

Fig. 18

Fig. 19


start
Calibration done ?
Yes
No
911
Put locator at (0,0) and Read $\Delta\varphi_A^{(I)}, \Delta\varphi_B^{(I)}$
912
$\Delta\varphi_A^{(0)} = \Delta\varphi_A^{(I)}$
$\Delta\varphi_B^{(0)} = \Delta\varphi_B^{(I)}$
913
Put locator at (x_c, y_c) and Read $\Delta\varphi_A^{(I)}, \Delta\varphi_B^{(I)}$
914
$\Delta\varphi_A = \Delta\varphi_A^{(I)} - \Delta\varphi_A^{(0)}$
$\Delta\varphi_B = \Delta\varphi_B^{(I)} - \Delta\varphi_B^{(0)}$
$\Delta r_A = r_{A_2} - r_{A_1}$
$\Delta r_B = r_{B_2} - r_{B_1}$
915
$k_A = \Delta r_A / \Delta\varphi_A$
$k_B = \Delta r_B / \Delta\varphi_B$
916
Initial P(i)=0
917
periodic trigger
910
Head in moving Read phases by trigger $\Delta\varphi_A^{(I)}, \Delta\varphi_B^{(I)}$
920
$\Delta r_A = k_A[\Delta\varphi_A^{(I)} - \Delta\varphi_A^{(0)}]$
$\Delta r_B = k_B[\Delta\varphi_B^{(I)} - \Delta\varphi_B^{(0)}]$
921
Solving roots for head position (x, y)
922
Take pixel position $[X(i), Y(i)]$ & status P(i)
923
Image data
924
all P(i)=1?
925
Yes
No
stop
926
$|x - X(i)| \le \delta_x$
$|y - Y(i)| \le \delta_y$
$P(i) = 0$
927
Yes
Take pixel color data
set P(i)=1
928
spray
929
Waiting for next trigger.
930
No such i at all
932
find the nearest point i
$|x - X(i)| \le D_x, |y - Y(i)| \le D_y$
933
move head by
$m_x = X(i) - x, m_y = Y(i) - y$
934

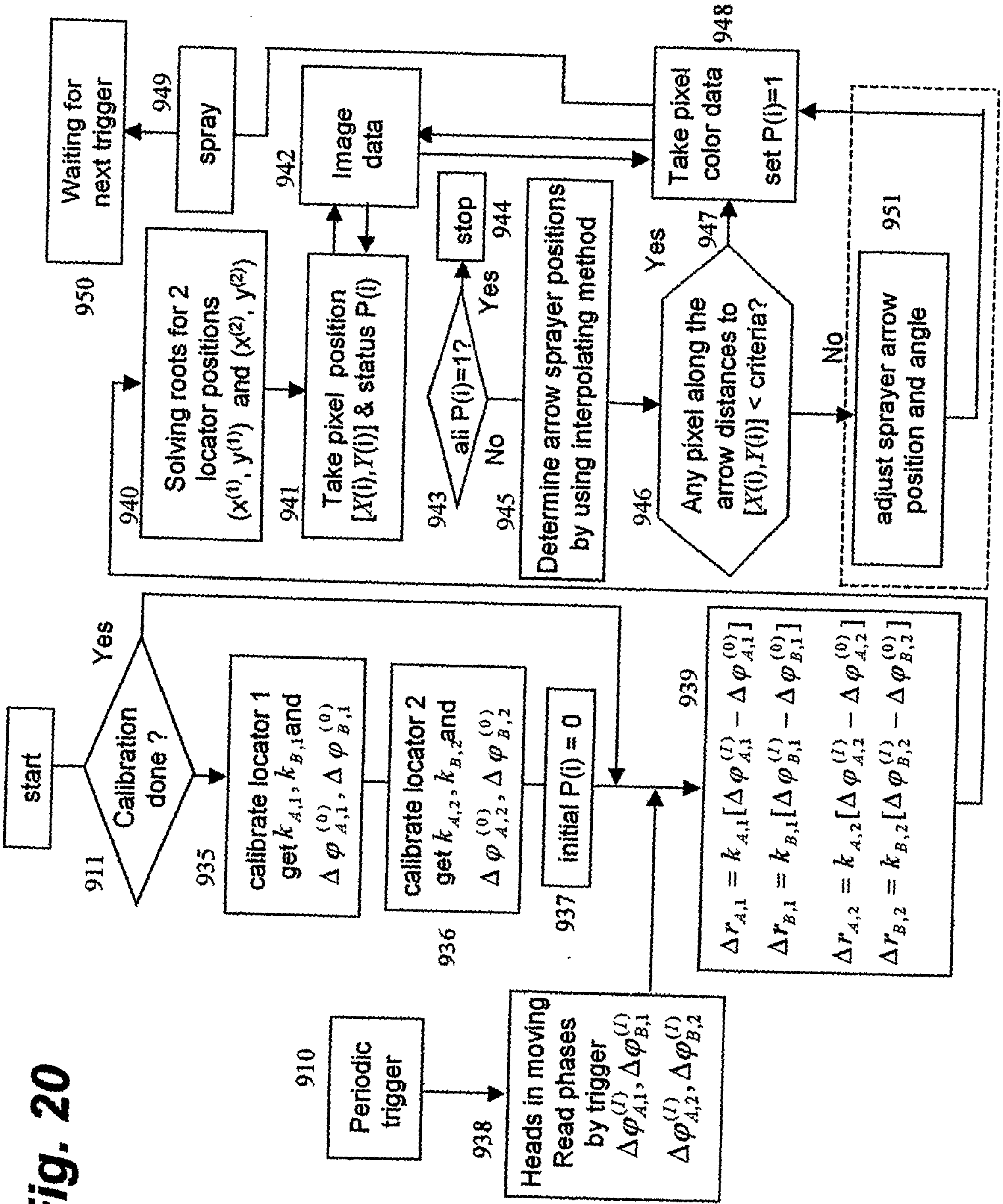

start
911
Calibration done ?
Yes
935
calibrate locator 1 get $k_{A,1}$, $k_{B,1}$ and $\Delta\varphi^{(0)}_{A,1}$, $\Delta\varphi^{(0)}_{B,1}$
936
calibrate locator 2 get $k_{A,2}$, $k_{B,2}$ and $\Delta\varphi^{(0)}_{A,2}$, $\Delta\varphi^{(0)}_{B,2}$
937
initial P(i) = 0
910
Periodic trigger
938
Heads in moving Read phases by trigger $\Delta\varphi^{(I)}_{A,1}$, $\Delta\varphi^{(I)}_{B,1}$ $\Delta\varphi^{(I)}_{A,2}$, $\Delta\varphi^{(I)}_{B,2}$
939
$\Delta r_{A,1} = k_{A,1}[\Delta\varphi^{(I)}_{A,1} - \Delta\varphi^{(0)}_{A,1}]$
$\Delta r_{B,1} = k_{B,1}[\Delta\varphi^{(I)}_{B,1} - \Delta\varphi^{(0)}_{B,1}]$
$\Delta r_{A,2} = k_{A,2}[\Delta\varphi^{(I)}_{A,2} - \Delta\varphi^{(0)}_{A,2}]$
$\Delta r_{B,2} = k_{B,2}[\Delta\varphi^{(I)}_{B,2} - \Delta\varphi^{(0)}_{B,2}]$
940
Solving roots for 2 locator positions $(x^{(1)}, y^{(1)})$ and $(x^{(2)}, y^{(2)})$
941
Take pixel position $[X(i), Y(i)]$ & status P(i)
942
Image data
943
all P(i)=1?
No
Yes
944
stop
945
Determine arrow sprayer positions by using interpolating method
946
Any pixel along the arrow distances to $[X(i), Y(i)]$ < criteria?
Yes
No
947
948
Take pixel color data set P(i)=1
951
adjust sprayer arrow position and angle
949
spray
950
Waiting for next trigger

Fig. 20

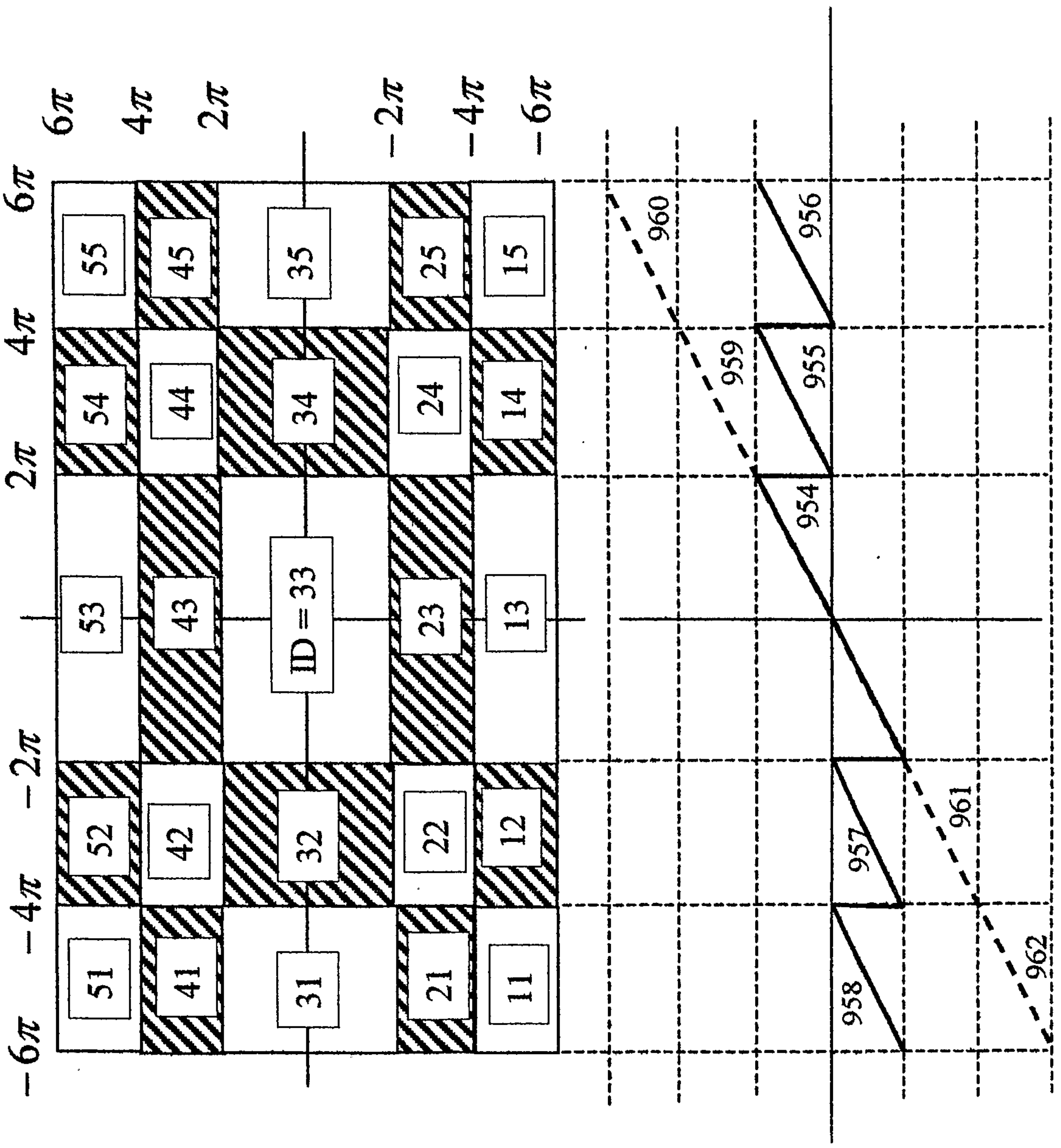

6π
4π
2π
−2π
−4π
−6π
55
45
35
25
15
54
44
34
24
14
53
43
ID = 33
23
13
52
42
32
22
12
51
41
31
21
11
954
955
956
957
958
959
960
961
962

Fig. 21

Fig. 22

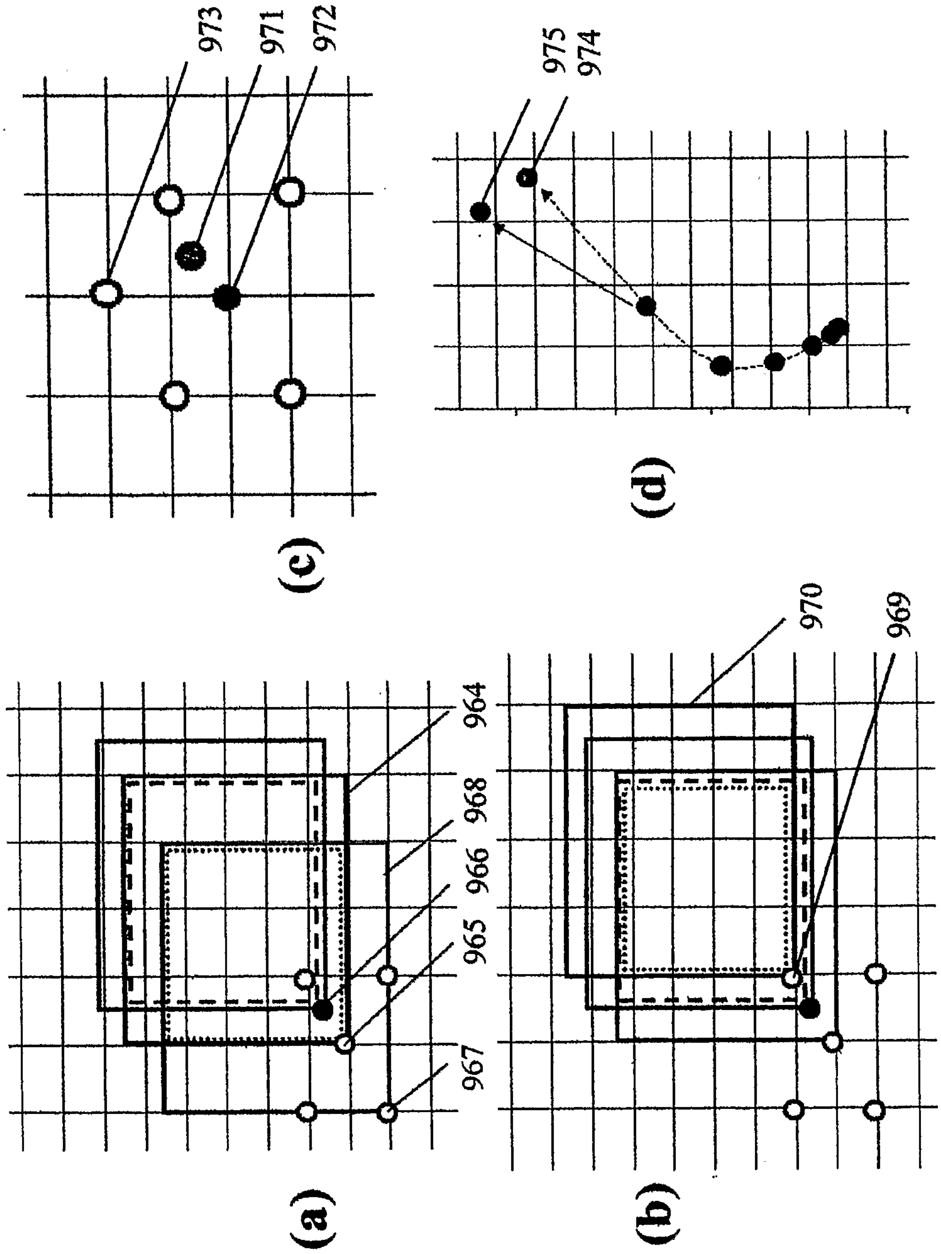
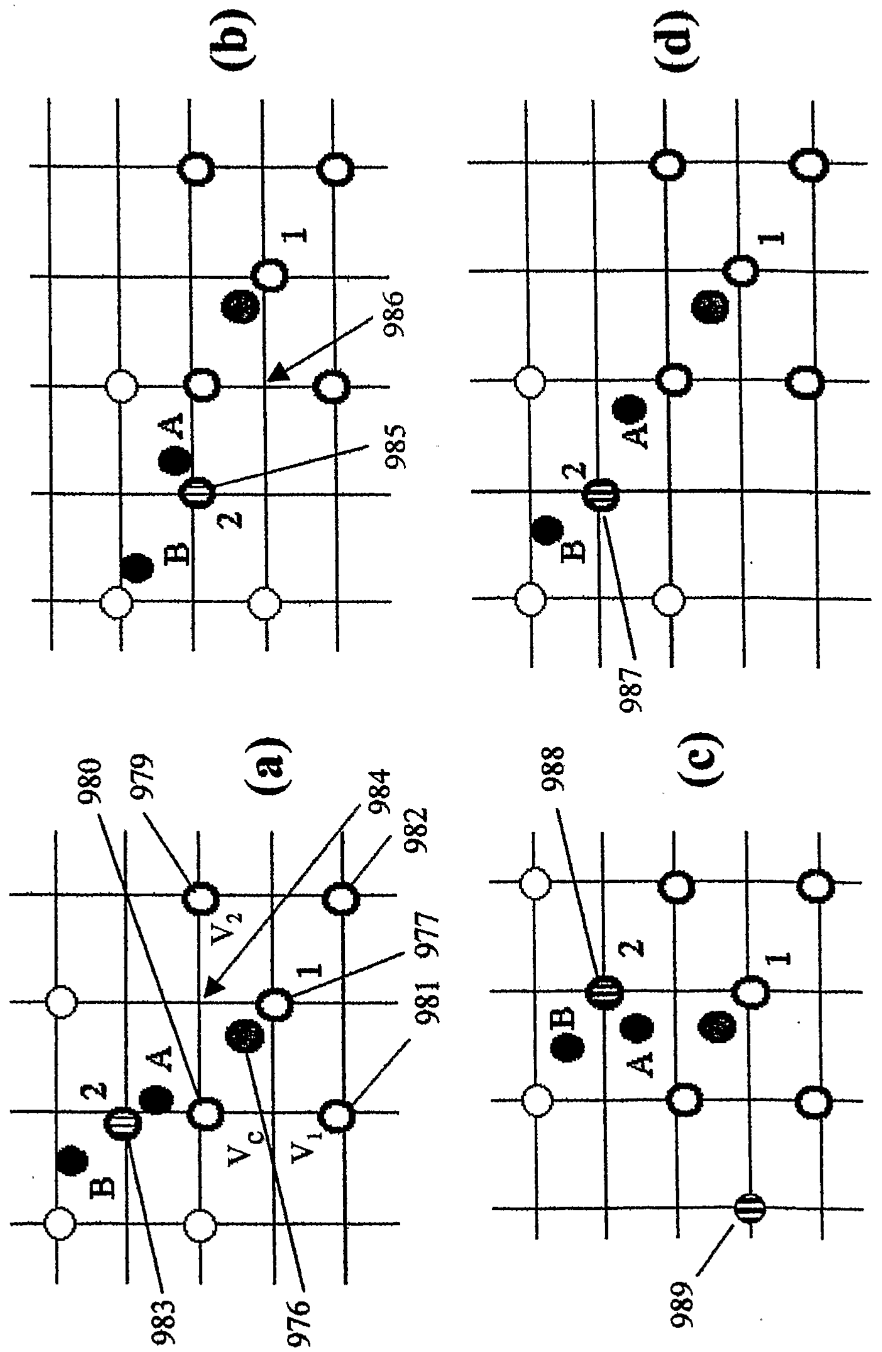


Fig. 23


(a)
(b)
(c)
(d)
A
B
1
2
V1
V2
Vc
976
977
979
980
981
982
983
984
985
986
987
988
989