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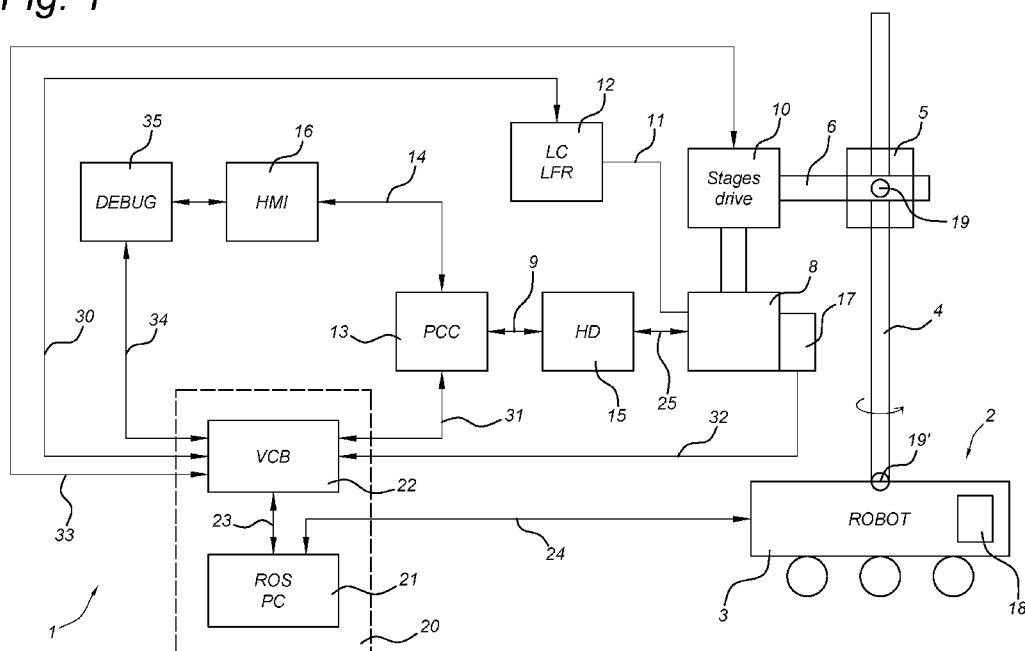
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(54) Title: PRINTING SYSTEM AND METHOD FOR PRINTING ON THREE-DIMENSIONAL SURFACES

Fig. 1



(57) Abstract: The invention relates to a printing system for printing on three-dimensional print surfaces. The system comprises a movable robot arm mounted on a movable support, a printhead supported on the robot arm and an ink supply device that is connected to the printhead via a fluid line for supplying ink to the printhead. A positioning system is connected to the support, the robot arm and to the printhead for measuring the position and orientation of the printhead. A compensation unit is connected to the printhead for mechanically positioning the printhead in a defined position. A control unit is operationally connected to: the positioning system for positioning the printhead in a predetermined print position, to the ink supply device for controlling the flow of ink to the printhead depending on a printhead orientation, and to the compensation unit for compensation of vibrational motions and/or positional errors of the support and of the robot arm, and maintaining the printhead in a defined position.



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Printing system and method for printing on three-dimensional surfaces

5 Field of the invention

The invention relates to a system and method for printing on a three-dimensional print surface, in particular to using a movable robot arm mounted on a movable support, a printhead supported on the robot arm and an ink supply device that is connected to the printhead via a fluid line for supplying ink to the printhead.

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Background of the invention

US 2016/0355026 describes a large robot system for printing on the hull or on the wings of an aircraft. A robot arm moves the printhead, that may be configured as an inkjet printer, in overlapping swaths of varying intensity across the aircraft's complex geometry.

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The problem of colouring and decorating objects of varying sizes and shapes is currently solved by dedicated designed solutions for such objects, like the ink printing on a battery or on the glass panels of mobile telephones. Key of these known inkjet systems is that the inkjet printing system is limited in movement and that the object is positioned in a defined position in relation to the inkjet system. However, many objects are complicated to handle in view of their size and/or shape, and in such cases an inkjet printing system which can freely move along the object, following the 3D contours, while ink jetting decorations needs to be provided with many integrated functions. The quality of the decoration and the process speed are key factors and a freely movable system needs to support these requirements in print resolution, process quality and consistency, coverage of the colour scheme, providing support for digital presented image input, speed of finishing the decoration of the object in m² per hour, as well as the capability to integrate the system in an automated support system like a 7-axis degree of freedom (DoF) robot mounted on a 3-axis DoF omni-directional wheels supported platform, to provide an autonomous solution.

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In regard of form and shape of the item on which an ink jet decoration is applied, the present invention seeks to present a system that manages the integrated complexity associated with facilitating electronic drop-on-demand printing with low viscosity printing inks on complex continuously contouring surfaces regardless of their orientation with respect to gravity. It is an object of the invention to provide a more rapid, high-quality and cost effect printing system than the known application of graphics on these types of shapes/surfaces and that comprise either a flat print being applied to the surface or a manual painting process which drives both cost and time, while requiring skilled labour.

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It is a further object of the present invention to provide a combination of novel components to realize an automated drop-on-demand process that will create complex full colour graphics on continuously contouring surfaces with coloured fluids, or inks, that are of low viscosity. This will include the control of the fluids that will provide the colour for the graphic, the ability to complete the image and manage the noise/motion effects from the automation hardware.

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Summary of the invention

Hereto, the invention provides a system for printing on a three-dimensional print surface comprising:

- a movable robot arm mounted on a movable support,
- 5 - a printhead supported on the robot arm,
- an ink supply device that is connected to the printhead via a fluid line for supplying ink to the printhead,
- a positioning system connected to the support, the robot arm and to the printhead for measuring the position and orientation of the printhead,
- 10 - a compensation unit connected to the printhead for mechanically positioning the printhead in a defined position, and

a control unit that is operationally connected to:

- the positioning system for positioning the printhead in a predetermined print position,
- the ink supply device for controlling the flow of ink to the printhead depending on a
- 15 printhead orientation, and
- the compensation unit for compensation of vibrational motions and/or positional errors of the support and of the robot arm, and maintaining the printhead in a defined position.

By moving the printhead along the complex three-dimensional contour of the print surface by the movable robot arm, large and complex print surfaces can be effectively printed at high quality and high speed. The positioning system of the robot provides a real time position control of the movable support, the robot arm and the printhead, and may include transponders on the support, a real time camera on the robot arm and/or a laser triangulation unit at or near the printhead to track stand-off of the printhead from the printing surface.

The pressure of the ink that is supplied by the ink supply device to the printhead from a bulk storage tank, via the ink supply line, is controlled to result in a predetermined pressure at the printhead for each printhead orientation, as the printhead moves across the three dimensional print surface. In a calibration step, in which a test pattern is printed at those printhead orientations that occur across the printing surface, the pressure values at each printhead orientation pertaining to the specific ink viscosity are recorded, and pressure curves for generating a substantially constant ink pressure at each printhead orientation may be stored in the control unit in the form of a formula or look-up tables.

During movement of the printhead across the print surface, vibrations in the robot arm or inaccuracies inherent in the robot manipulator are compensated by the controller according to the invention in real time on the basis of the positional data of the printhead, for instance by actuating x-y or z movements of the printhead, relative to the print surface.

In a preferred embodiment the printhead is a printhead of the recirculating type. In such printheads, ink is continuously circulated through the printhead, and a portion of the printhead that is not ejected through nozzles of the printhead may be recirculated back to the ink supply. Some advantages

of using a printhead of the recirculating type are that the temperature of the ink in the printhead can more easily be controlled, and that the ink can more easily be kept in jettable condition.

In an embodiment, the ink supply device is mounted on the moveable support, at a distance of at least 1 m from the printhead.

5 In an embodiment, the moveable support is provided with wheels and/or tracks for driving across a floor. The moveable support, also denoted mobile support, can thus be driven around the three dimensional object onto which the ink is to be deposited. Preferably the moveable support is provided with omnidirectional wheels, such as Mecanum wheels.

10 In an embodiment the system comprises an inflow pressure sensor at or near an ink inlet of the printhead for measuring an inflow pressure of the ink, a recirculation pressure sensor for measuring a recirculation pressure at a recirculation outlet of the printhead, and wherein the controller is adapted for controlling the flow of ink from the ink supply device to the printhead depending on the inflow pressure and the recirculation pressure in a manner ensuring that a lowest of these pressures is above a predetermined lowest ink pressure operating value for operating the printhead. Thus, the system can
15 control the flow of ink to the printhead based on the printhead orientation, as well as on the inflow pressure and the recirculation pressure. Generally, based on the orientation of the printhead a rough estimate of the pressure in the printhead can be estimated, which estimate can be combined with more fine grained measured inflow and recirculation pressure to obtain a highly more accurate indication of the actual inflow and recirculation pressure. Ensuring that the lowest of the pressures remains above
20 the predetermined lowest ink pressure operating value is typically achieved by controlling a pump that is connected between the ink supply device and the printhead.

The system is preferably adapted for providing data regarding the pressures to the controller at least once every 10 ms, to ensure that the ink pressure in the printhead can be kept above the predetermined lowest in pressure value for operating the printhead. The predetermined lowest ink
25 pressure operating value for operating the printhead depends on the printhead and is generally provided by the printhead manufacturer. However, this value may be dependent on the ink that is used as well.

In an embodiment the controller is adapted for controlling the flow of ink from the ink supply device to the printhead depending on the inflow pressure and the recirculation pressure in a manner ensuring that a highest of these pressures is below a predetermined highest ink pressure operating
30 value for operating the printhead for the ink used.

In an embodiment the inflow pressure sensor is arranged directly upstream from the printhead, and the recirculation pressure sensor is arranged directly downstream from the printhead. Though in this embodiment the pressure sensors are located outside of the printhead, they are arranged sufficiently close to the printhead to measure an indication of the ink pressure in the printhead. Preferably, both
35 pressure sensors are arranged within 10 cm from the interior of the printhead where ink is held.

In an embodiment wherein the sensors are spaced apart from each other by at least 5 cm, preferably by at least 10 cm, more preferably by between 10 cm and 50 cm. For instance, the inflow pressure sensor may be arranged on one side of the printhead, and the recirculation pressure sensor may be arranged on another side of the printhead, preferably on an opposite side of the printhead. By
40 spacing the sensors apart it is ensured that they can measure different ink pressures.

In an embodiment the ink supply device comprises a main ink supply and a pump for pumping ink from the main ink supply to the printhead. The pump generally is located together with the main ink supply on the moveable support. Preferably, one or more ink tanks are provided on the robot arm, and one or more corresponding pumps are provided between the further tank(s) and the printhead to supply ink to the printhead. The one or more ink tanks are preferably arranged within 1m of the printhead, preferably within 10 cm thereof, but in any case closer, when seen along an ink flow path, than the main ink supply. Each ink tank preferably is adapted for containing a volume of ink that is greater than the inner volume of the printhead for containing ink.

In an embodiment, the system further comprises one or more ink tanks provided on the robot arm downstream of the main ink supply and pump, and one or more corresponding pumps provided on the robot arm between the one or more ink tanks and the printhead to supply ink to the printhead, preferably wherein the one or more ink tanks are preferably arranged within 3m of the printhead and closer to the printhead, when seen along an ink flow path, than the main ink supply is. Preferably, two or more of said corresponding pumps are provided on the robot arm, one of which is arranged for circulating ink from the ink supply through the refill channel, and another of which is arranged for circulating ink from the ink supply through the recirculation channel.

In an embodiment in which the printhead is of the recirculation type, the printhead comprises an internal refill channel and an internal recirculation channel, and further comprises a first ink inlet and a first ink recirculation outlet, wherein the system is adapted in such a manner that, during use, ink is supplied to printhead only through the first ink inlet and ink is returned to the ink supply only through the first ink recirculation outlet. Generally in this embodiment, the rate of flow of ink through the internal recirculation channel is at least 7 times greater than the rate of flow of ink through the internal refill channel.

In another embodiment in which the printhead is of the recirculation type, the printhead comprises an internal refill channel and an internal recirculation channel, and the printhead further comprises:

a first ink inlet connected to the refill channel and a first ink recirculation outlet connected to the ink refill channel,

a second ink inlet connected to the recirculation channel and a second ink recirculation outlet connected to the recirculation channel;

wherein the system is adapted in such a manner that, during use, ink is supplied to printhead through both the first ink inlet and the second inlet, and ink is returned to the ink supply through both the first ink recirculation outlet and the second ink recirculation outlet.

In this system, the rate of flow of ink to the refill channel is preferably within 25% of the rate of flow of ink to the recirculation channel. For instance, if the rate of ink flow to the refill channel is 10 ml / sec, then the rate of ink flow to the recirculation channel is between 7,5 and 12,5 ml / sec. Preferably the pump is arranged for circulating ink from the ink supply through the refill channel, and the system further comprises a second pump for circulating ink from the ink supply through the recirculation channel.

In an embodiment the printhead is provided with one or more dampers at an ink inlet side of the printhead, for reducing shock waves of ink in the printhead due to acceleration of the printhead relative to the print surface.

5 In an embodiment in which the printhead is of the recirculation type, the printhead is provided with one or more dampers at an ink recirculation outlet side of the printhead for reducing shock waves of ink in the printhead due to acceleration of the printhead relative to the print surface.

In an embodiment the system further comprises a temperature sensor arranged for measuring a temperature of the ink at the printhead, and a temperature conditioning system adapted for conditioning the temperature of ink that is supplied to the printhead to a predetermined temperature
10 range. The predetermined temperature range will generally depend on the type of ink used as well as the type of printhead that is used.

In an embodiment the system is adapted for printing on a substantially stationary 3D surface while moving the printhead relative to the stationary 3D surface. Thus, the surface on which a pattern is to be printed can remain stationary, e.g. relative to the floor, while the robot arm is moved relative to the
15 floor in three dimensions.

The compensating system of the present invention is particularly effective on a large robot according to the invention that may be used for printing on large objects, such as vehicles, for instance airplanes. Such a large robot may comprise a vertical arm of a height of at least 10 m, preferably about
20 13 m and a transverse arm that is displaceable along the vertical arm in a vertical direction and in a transverse direction, the transverse arm having a length of at least 5 m, preferably about 13 m, the printhead being situated at the end of the transverse arm.

In an embodiment of a printing system according to the invention, the printhead comprises an array of an ink jet nozzles, the ink supply device comprising an inflow pressure sensor and a recirculation
25 pressure sensor at or near the nozzles for measuring an inflow pressure at an inflow end that is situated upstream of the array of nozzles and a recirculation pressure at an outflow end that is situated downstream of the array of nozzles, the controller operating the ink supply device and pressurises the ink in dependence on the orientation of the printhead. The ink supply system may for instance be a low flow recirculation supply system of the type LC-LFR as available from the company Megnajet,
30 Northamptonshire, United Kingdom.

An embodiment of the system according to the present invention can support either 4, 6 or 7 colour schemes. With the 6 colour scheme (YMCK + Green + Orange) more than 90% of the Pantone colour definition can be printed on a white background. With adding the white ink colour, the white background can be created or further improved to realize a predefined colour quality, or used for print
35 correction of an certain area by first printing white ink on top of the print error and then reprinting this area.

The system according to the invention will print digitally presented images that are presented as input. A standard interface is provided for input of a digital image to print by the system. The input image supports the print resolution and the scaling of the image. The system is optimised to handle the

relatively large amount of data of large pictures, the decomposition towards each colour, and the real-time process of supplying data to the print system in relationship to the print swaths.

The speed of finishing the decoration of the object in m² per hour can be optimized for the minimum total around time for the object. The system according to the invention may be provided with a bidirectional print function to limit the automation path reorientation for each printing swath and increasing the performance.

According to a further aspect, the present invention provides a method for printing on a stationary three dimensional surface using a mobile robot, wherein the mobile robot comprises a moveable support, a robot arm moveably mounted on said moveable support, a printhead supported on the robot arm, and an ink supply device connected to the printhead via a fluid line, the method comprising:

- positioning the printhead in a predetermined position relative to the three dimensional surface;
- determining an orientation and position of the printhead;

- controlling the printhead to move in order to compensate for vibrational motions and/or positional errors of the support and of the robot arm, based on the measured orientations and positions;

- measuring an inflow pressure of the ink directly upstream of the printhead; and

- controlling the flow of ink from the ink supply device to the printhead depending on the printhead orientation and on the inflow pressure in a manner ensuring that the inflow pressure is above a predetermined lowest ink pressure operating value for operating the printhead.

In an embodiment, the printhead is a printhead of the recirculation type and the method further comprises measuring an recirculation pressure of the ink directly downstream of the printhead, and controlling the flow of ink from the ink supply device to the printhead depending on the recirculation pressure in a manner ensuring that the recirculation pressure is below a predetermined highest ink pressure operating value for operating the printhead.

In an embodiment, said controlling of the flow of ink from the ink supply to the printhead is carried out while the printhead prints a pattern on the three dimensional surface and/or while the printhead is moved relative to the three dimensional surface.

In an embodiment, the method is carried out using the system of the present invention, with the moveable support, the moveable robot arm, and the ink supply device of the robot used in the method corresponding to the moveable support, the moveable robot arm, and the ink supply device of the system of the invention. Preferably, the mobile robot has a height of at least 10 m and a transverse arm that is displaceable along the vertical arm in a vertical direction and in a transverse direction, the transverse arm having a length of at least 5 m, the printhead being situated at the end of the transverse arm.

Brief description of the drawings

A schematic lay-out of a printing system according to the invention will by way of non-limiting example be described in detail with reference to the accompanying drawings. In the drawings:

Fig. 1 shows the schematic lay-out of the printing system according to the invention,

Fig. 2 shows a large autonomously moving robot for use in a printing system according to the invention,

Figs 3A – 3C shows a schematic embodiment of different printheads suitable for use in the system of the invention, and Fig. 3D shows a schematic bottom side view of these printheads, and

Figs. 4A, 4B and 4C schematically illustrate different flow circuits for ink, as may be used in the present invention.

Detailed description of the invention

Fig. 1 shows a schematic representation of a printing system 1, comprising a movable robot 2. The robot 2 has a moveable, i.e. mobile, support 3, carrying a vertical mast 4 of a height of 13 m along which a carriage 5 can travel up and down. The carriage 5 supports a transverse arm 6 of a length of 13 m that is movable in a transverse direction. At the end of the arm 6, a printhead 8 is supported. The printhead 8 is mounted on an x,y,z stage 10 for displacement relative to a three-dimensional print surface, in an x,y plane that is parallel to the print surface and in a z direction that is perpendicular to the print surface. A suitable robot for supporting the printhead 8 is described in US patent application nos. 16/015,240 and 16/015,243 filed on 22 June 2018, and is shown in Fig. 2. Fig. 8 shows an inertia measurement unit (IMU) 8a that is fixed to the printhead 8, for measuring an orientation of the printhead in particular with respect to the direction of gravity. The carriage 5 and mast 4 are provided with encoders 5a and 4a, respectively for keeping track of a translation and rotation of arm 6 relative to the mast 4, and for keeping track of a translation about a vertical axis of the mast relative to the support 3.

In the system of Fig. 1, the printhead 8 may be formed by an ink jet printer of type Fujifilm Dimatix Part Number SG1024LA-2C and is connected by fluid lines 11 to an ink supply unit 12 for supply of ink to the printhead 8. The ink supply unit 12 may comprise a low flow recirculation pump system, available from Megnajet, Northamptonshire, United Kingdom.

A print controller 13 is connected to head drives 15 that operate the nozzles of the printhead 8 via a customised interface 9. The head drives 15 are shown in this embodiment to be connected to the printhead 8 via a connection 25 but can also be integrated in the printhead 8. The print controller 13 decomposes the image that is to be printed and transforms the colour values of the pixels in the image into discrete voltages that are input to the printhead 8. The image to be printed can be entered via a human-machine interface, such as a terminal 16, and is transmitted to the print controller 13 via Ethernet connection 14.

A positioning system comprises a position sensor 17 for real-life determination of the position of the printhead 8 relative to a print surface, such as by laser triangulation and/or camera's. The positioning system furthermore includes a displacement sensor 18 that may comprise an inertial measurement unit (IMU), optical sensors and/or transponders or RFID sensors for determining the robot position. It may also include transducers 19, 19' situated on the linking segments of the movable robot parts and/or on the wheels of the support 3, for determining the position and orientation of the robot arms 4,6.

A central control unit 20 comprises a robot operating system/print control unit 21 and a printhead position control unit 22, interconnected via an Ethernet connection 23. The robot operating system 21

is connect to the robot 2 via an Ethernet connection 24 to communicate with the displacement sensor 18 and the transducers 19,19' for controlling the position of the robot 1.

The printhead position control unit 22 is connected to the ink supply unit 12 via a RS-485 connection 30, and is connected to the print controller 13 via a digital input/out 31 for controlling the pressures of the ink that is supplied to the printhead 8 via the ink supply unit 12.

The printhead position control unit 22 is connected to the position sensor 17 via signal line 32 and/or to the displacement sensor 18 (in the present embodiment shown as a wireless connection) for receiving position and orientation data for the printhead 8.

An EtherCat connection 33 connects the printhead position control unit 22 to the x,y,z stages of the printhead 8 for vibration control and positional corrections of the printhead 8.

A debug terminal 35, which may be combined with the input terminal 16, is connected to the printhead position control unit 22 by Ethernet connection 34.

The pressure control system 13 consists of a primary Pressure Control Unit that sets meniscus and recirculation pressures of the ink jet nozzles of the printhead 8, an off-board manifold that consists of solenoids and pressure sensors that are within 14 cm of the print face, and pressure reading and control software that responds to the pose or orientation of the printhead faces.

The pressure control system 13 comprises a computer program for the conversion data files to print signals.

The printhead position control unit 22 preferably is a real-time control system, wherein the position sensor 17 may comprise but is not limited to the a combination of one or more real-time cameras that acquire images at a minimum of 30 frames per second, and an inertial measurement unit, where the output data is combined in the control unit 22 to generate a state and position estimate of the robot 2 and the printhead 8 that can continuously enable the tracking of a reference feature. This will also include the means to track stand-off of the print face from the printing surface via laser triangulation to maintain proper ink face stand-off.

The printhead position control unit 22 comprises a computer program for vision and real time tracking.

Stages and drives 10 form a compensation system that mitigates gross and small errors due to system vibration or inaccuracies inherent to traditional manipulator approaches. These stages may be mounted on the final axis to compensate for any variation experienced within the system to enable compensation based on read information from the real-time system 17, 22 actuating the stages in x, y, and, if required z relative to the print surface and direction. Encoder output from the robot encoders 19, 19' may be utilised to control the position and orientation of the printhead 8.

Head drives 15 enable the communication of the decomposed image into the discrete voltages that need to be driven to the nozzles of the printhead 8. The software, known as "ripping" software decomposes a multi-colour image into its 4, 6 or 7 colour components depending on ink configuration, and provides the bits to the print driver that deliver the voltage signals to the discrete arrays of nozzles of the printhead 8 as dictated via the output of the rip software.

The robot operating system/print control unit 21 provides state and gross movement and manipulation of a printing end effector that is mounted to the end extent of a manipulator at the end of the transverse robot arm 6.

The robot operating system/print control unit 21 comprises a computer program for pressure control and machine state control.

Finally, a control computer 16, 35 is provided with an interface enabled for user control and set up, monitoring, and maintenance or trouble shooting of the process, as well as lower bandwidth process monitoring, in particular the correlation of the orientation of the printhead 8 to adjust the pressure control system 13 to support the multi-orientation continuous curvature printing.

The control computer 16,35 comprises a computer program for image file processing.

Three Dimensional inkjet Process System Execution and Control

The three dimensional printing system described above contains the stated parts that share information in a logical fashion and work cooperatively. The system is not limited to the configuration that has been specifically disclosed including separate real-time vision based control hardware 22 for the real-time vision control, with separate lower bandwidth separate PC 21 for pressure control. Variations are intended to be merged onto one central computational processing unit where a large number of different types of sensors and cameras may be leveraged that offer additional advantages relative to resolution, frame rate, and performance.

The various communication steps of the print execution flow listed below facilitate the primary function of the creation of a detailed full-coloured graphic over a 3 dimensional contoured print surface:

1. Robot 2 gross move to new location; Robot 2 signals Move Complete and Ready to Spit to robot operating system/print control unit 22 /VCB; Robot 2 waits to move.
2. Control unit 22 gets Robot position, calculates ink pressures, controls and verifies ink supply unit 12 (LC-LFR); Control unit 22 signals Spit to terminal/ HMI 16 (via pressure control system 13/PCC) (it should be noted that spit occurs between all macro moves).
3. Terminal/HMI 16 Spit; signals Spit Complete to control unit 22/VCB (again, via pressure control system 13/PCC).
4. Control unit 22/VCB signals Ready to Move to Robot 2, activates Z-axis control.
5. Robot 2 moves to print standoff distance; Robot 2 signals Swath Print, Swath Direction, and Move Complete to Control unit 22 /VCB; Robot 2 waits to move.
6. Swath Print = 0, just a move; Swath Print = 1, we are printing an image.
7. Control unit 22/ VCB seeks index, initializes position sensor 17/IMU 18, stabilizes Y axis, estimates encoder (X), updates encoder output (TBD), signals Print Enable to terminal 16/ HMI, signals Ready to Move to Robot.
8. Robot 2 moves along swath; Control unit 22/VCB stabilizes & outputs encoder; printer prints a swath.
9. Robot 2 moves past final index; (Control unit 22/VCB encoder is digital pulse generated); Robot signals Swath Complete.

10. Swath Complete will be Swath Print set 1 to 0, or vice versa via digital I/O.
11. Control unit 22/VCB has error if encoder estimate is invalid.
12. Control unit 22/VCB signals Print Disable to terminal 16/HMI; disables Z control; withdraws Z.
13. Robot 2 Withdraws along Z (swath printing loop can end here).

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On top of these primary printing states, additional top-level states may be applied to facilitate safety implementation and control of maintenance and debug processes:

1. Start up (may be a subset or a complete self-test & communication / system test)
- 10 2. Printing Process States (multiple, looping)
3. Safety states
4. Retract z axis fully and center y axis
5. Error States
6. Maintenance and Utility States
- 15 7. Purge
8. Spit
9. Sinusoid stage motion
10. Self-test: Camera, lighting, IMU 1&2 self-test (requires known EoAT state)
11. Communications / system test (verify LC-LFR, printer, robot status)

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The combination of all the components of the printing system according to the invention, and the way they interact provide a complex contour capable drop-on-demand or inkjet printing system. The components may be interchanged but the function that they provide and the minimum performance that is executed, as well as how information is exchanged between the components provide a unique capability for complex graphic creation, irrespective of print surface orientation or gravity.

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Examples of suitable printheads

Figs. 3A, 3B and 3C each show a schematic embodiment of a printhead as may be mounted on a robot arm in the system of the invention, and Fig. 3D shows a bottom side view a nozzle plate 301 as is used in each of these printheads. During printing, ink is ejected through the nozzle plate 301 onto the surface to be printed. Electrical signals for controlling printing by the printhead as well as electrical power for operating the printhead, are provided through signal and power cable 305.

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The printhead 300 shown in Fig. 3A is of the recirculation type and includes an ink inlet 311 for receiving ink, and an ink recirculation outlet 331 for discharging ink to be recirculated. Connected to the inlet 311 is a conduit 310 for providing ink to the printhead 300, and an conduit 330 is connected to the outlet for transporting ink to be recirculated away from the printhead. An inflow pressure sensor 312 is provided directly upstream from the inlet of the printhead for measuring an pressure of the ink at a first side of the printhead. A recirculation pressure sensor 332 is provided directly downstream from the outlet of printhead for measuring a pressure of the ink at a second side of the printhead, and the two sensors are arranged for measuring a pressure indicative of ink pressure at two different sides in the

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printhead. Just upstream from the inflow pressure sensor 312, and just downstream from the recirculation pressure sensor 332, respective dampers 313, 333 are provided, for damping sudden changes in ink pressure in the printhead that may be caused by changes in orientation and/or by acceleration of the robot arm relative to the moveable support. Though not shown in Fig. 3A, but
5 illustrated in Fig. 4A, within the printhead there is an ink circuit comprising both a refill channel and a recirculation channel.

The printhead 300' shown in Fig. 3B is also of the recirculation type, but in this case the printhead is provided with separate ink inlets 311, 321 connected respectively to an internal refill channel of the printhead and an internal recirculation channel of the printhead. Likewise, separate ink
10 recirculation outlets 331, 341 are provided for recirculating ink back to the ink supply. Conduits 310, 320 connect respectively to the inlets 311, 321, and conduits 330, 340 connect respectively to outlets 331, 341. Here, directly upstream of each of the inlets 311, 321 a respective inflow pressure sensor 312, 312 is provided, and directly downstream of each of the outlets 331, 341 a respective recirculation pressure sensor 332, 342 is provided. Dampers 313, 323 and 333, 344 are provided just upstream from
15 the inflow pressure sensors, and just downstream from the recirculation pressure sensors.

Fig. 3C shows yet another printhead 300'' as may be mounted on the robot arm of the invention, wherein the printhead is of the non-recirculating type having only a single ink inlet 311, a single inflow ink pressure sensor 312, and a damper 313.

Fig. 3D shows a bottom view of the printheads of Figs. 3A, 3B and 3C. The bottom of these
20 printheads comprises a nozzle plate 301. The nozzle plate comprises a number of rows 302a, 302b, 302c, 302c of nozzles, each row containing at least 24 separate nozzle openings. The different rows of nozzles can be used for depositing different colors of ink. For example, the first jet row 302a may deposit red ink, while the row 302b next deposits green and the next row 302c blue. The image is formed when very small colored droplets are deposited so close to one another that they appear
25 to cover the surface. It is important that the individual colored droplets do not contact one another, while still wet, to avoid the droplets from coalescing and forming an unintended color.

Examples of flow of ink through the system of the invention

Figs. 4A, 4B and 4C schematically show how ink may flow through the system of the invention,
30 when using a printhead of Fig. 3A, 3B or 3C respectively.

Fig. 4A shows a main ink supply 401, a temperature control device 403 for conditioning ink from the main ink supply to a temperature within a predetermined temperature range, and a main pump 402 connected between the main ink supply 401 and the temperature control device. The main ink supply 401, the main pump 402 and the temperature control device 403 are located on the movable support of
35 the system, e.g. the support 3 of Fig. 2. The temperature control device is in fluid connection, via damper 410, with an ink tank 411 that is arranged on the robot arm and which acts as a buffer for storing ink close to printhead 440. Portions of the systems of Figs. 4A-4C that are surrounded by a dotted line, are all arranged on the robot arm. During printing, the distance between the main ink supply and the printhead will typically be more than 6 meters, and by placing buffer tank 411 on the robot arm,
40 responsiveness of the system is improved, and in particular the flow of ink to the printhead, and thus the

pressure of ink in the printhead, can be quickly adjusted be within a predetermined range of printhead ink pressure operating values.

Downstream from the ink tank 411, a further pump 412 is arranged on the robot arm for pumping ink from the ink tank 411, via damper 430 and inflow pressure sensor 440, into the printhead 450 that is mounted on the robot arm. The printhead 450 may be a printhead as shown in Fig. 3A. Recirculated ink leaves the printhead past recirculation pressure sensor 442 and then damper 432. As indicated above, by providing the ink tank 440 on the robot arm, i.e. closer to the printhead than the main ink supply 401, it is possible to quickly adjust the flow of ink to the printhead.

Fig. 4B shows a main ink supply 401, temperature control device 415, pump 411 connected to an ink tank 440. Here too, the elements within the dotted rectangle are arranged on the robot arm, whereas the main ink supply 401, main pump 302 and the temperature control device 403 are arranged on the moveable support. In the embodiment of Fig. 4B, the printhead, which may be the printhead of Fig. 3B, comprises separate inlets for the refill and recirculation channels as well as separate outlets therefor. Two separate further pumps 412, 413 are provided on the robot arm for pumping ink towards the printhead 450. Inflow pressure sensors 440, 441 are arranged directly upstream from the printhead and connected respectively to a refill channel and a recirculation channel of the printhead. Recirculation pressure sensors 442, 443 are arranged directly downstream from the printhead 450, for measuring the recirculation pressure at the outlets of the printhead. Dampers 430 - 433 are provided for reducing sudden changes in pressure of ink in the printhead due to acceleration of the robot arm. Pump 412 can be individually controlled based on the output from sensors 440, 442 to adjust the ink pressure in the refill channel, and pump 413 can be individually controlled to adjust the pressure in recirculation channel to the respective predetermined ink pressure operating values for the printhead.

Fig. 4C shows a main ink supply 401, pump 402 and temperature control device 403, which are arranged on the moveable support, and an ink tank 411, pump 412 that are arranged on the robot arm and are in fluid connection with the printhead 450. The printhead, which may be the printhead of Fig. 3C, is of the non-recirculating type. However, it is still possible to estimate the ink pressure in the printhead based on the data from the IMU, and on the data from inflow pressure sensor 440. The controller of the robot can control the pump 412 to ensure that the pressure measured by sensor 440 remains above a predetermined lowest operating ink pressure of the printhead.

Claims

1. System for printing on a three-dimensional print surface comprising:

- a movable robot arm mounted on a movable support,
- 5 - a printhead supported on the robot arm,
- an ink supply device that is connected to the printhead via a fluid line for supplying ink to the printhead,
- a positioning system connected to the support, the robot arm and to the printhead for measuring the position and orientation of the printhead,
- 10 - a compensation unit connected to the printhead for mechanically positioning the printhead in a defined position, and
- a control unit that is operationally connected to:
 - the positioning system for positioning the printhead in a predetermined print position,
 - the ink supply device for controlling the flow of ink to the printhead depending on a
 - 15 printhead orientation, and
 - the compensation unit for compensation of vibrational motions and/or positional errors of the support and of the robot arm, and maintaining the printhead in a defined position.

2. System according to claim 1, wherein the printhead is a printhead of the recirculating type.

3. System according to claim 2, comprising an inflow pressure sensor at or near an ink inlet of the printhead for measuring an inflow pressure of the ink, a recirculation pressure sensor for measuring a recirculation pressure at an ink recirculation outlet of the printhead, and wherein the controller is adapted for controlling the flow of ink from the ink supply device to the printhead depending on the inflow pressure and the recirculation pressure in a manner ensuring that a lowest of these pressures is above a predetermined lowest ink pressure operating value for operating the printhead.

4. System according to claim 3, wherein the controller is adapted for controlling the flow of ink from the ink supply device to the printhead depending on the inflow pressure and the recirculation pressure in a manner ensuring that a highest of these pressures is below a predetermined highest ink pressure operating value for operating the printhead for the ink used.

5. System according to any one of claims 2-4, wherein the inflow pressure sensor is arranged directly upstream from the printhead, and the recirculation pressure sensor is arranged directly downstream from the printhead.

6. System according to any one of claims 2-5, wherein the sensors are spaced apart from each other by at least 5 cm, preferably by at least 10 cm, more preferably by between 10 cm and 50 cm.

7. System according to any one of claims 2-6, wherein the printhead comprises an internal refill channel and an internal recirculation channel, and further comprises a first ink inlet and a first ink recirculation outlet, wherein the system is adapted in such a manner that, during use, ink is supplied to printhead only through the first ink inlet and ink is recirculated to outside of the printhead only through the first ink recirculation outlet.

8. System according to any one of claim 2-7, wherein the printhead comprises an internal refill channel and an internal recirculation channel, and further comprises

a first ink inlet connected to the refill channel and a first ink recirculation outlet connected to the ink refill channel,

a second ink inlet connected to the recirculation channel and a second ink recirculation outlet connected to the recirculation channel;

wherein the system is adapted in such a manner that, during use, ink is supplied to printhead through both the first ink inlet and the second inlet, and ink is recirculated to outside of the printhead through both the first ink recirculation outlet and the second ink recirculation outlet.

9. System according to any one of the preceding claims, wherein the ink supply device comprises a main ink supply and a pump for pumping ink from the main ink supply to the printhead.

10. System according to claim 9, further comprising one or more ink tanks provided on the robot arm downstream of the main ink supply and pump, and one or more corresponding pumps provided on the robot arm between the one or more ink tanks and the printhead to supply ink to the printhead, preferably wherein the one or more ink tanks are preferably arranged within 3m of the printhead and closer to the printhead, when seen along an ink flow path, than the main ink supply is.

11. System according to claim 10 when dependent on claim 8, wherein two or more of said corresponding pumps are provided on the robot arm, one of which is arranged for circulating ink from the ink supply through the refill channel, and another of which is arranged for circulating ink from the ink supply through the recirculation channel.

12. System according to any one of the preceding claims, wherein the printhead is provided with one or more dampers at an ink inlet side of the printhead, for reducing shock waves of ink in the printhead due to acceleration of the printhead relative to the print surface.

13. System according to any one of the preceding claims when dependent on claim 2, wherein the printhead is provided with one or more dampers at an ink recirculation outlet side of the printhead for reducing shock waves of ink in the printhead due to acceleration of the printhead relative to the print surface.

14. System according to any one of the preceding claims, further comprising a temperature sensor arranged for measuring a temperature of the ink at the printhead, the system further comprising temperature conditioning system adapted for conditioning the temperature of ink that is supplied to the printhead to a predetermined temperature range.

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15. System according to any one of the preceding claims, the system is adapted for printing on a substantially stationary 3D surface while moving the printhead relative to the stationary 3D surface.

10 16. System according to any one of the preceding claims, wherein the printhead comprises an array of an ink jet nozzles, the ink supply device comprising an inflow pressure sensor and a recirculation pressure sensor at or near the nozzles for measuring an inflow pressure at an inflow end that is situated upstream of the array of nozzles and a recirculation pressure at an outflow end that is situated downstream of the array of nozzles, the controller operating the ink supply device and pressurises the ink in dependence on the orientation of the printhead.

15

17. System according to any one of the preceding claims, wherein the positioning system comprises an optical device for measuring the distance of the printhead from a print surface.

20 18. System according to any one of the preceding claims, wherein the positioning system comprises at least one camera mounted at or near the printhead providing images at a rate of at least 10 frames/s.

19. System according to any one of the preceding claims, wherein the positioning system comprises encoders attached to robot arm segments.

25 20. System according to any one of the preceding claims, wherein the positioning system comprises an inertia measurement unit connected to the robot.

21. System according to any one of the preceding claims, wherein the compensation unit comprises actuator members for displacing the printhead in directions substantially parallel to a printing surface.

30

22. System according to claim 21, wherein the compensation unit comprises an actuator member for displacing the printhead in a direction that is transverse to a printing surface.

35 23. System according to any one of the preceding claims, wherein the robot comprises a vertical arm of a height of at least 10 m and a transverse arm that is displaceable along the vertical arm in a vertical direction and in a transverse direction, the transverse arm having a length of at least 5 m, the printhead being situated at the end of the transverse arm.

40 24. Method for printing on a stationary three dimensional surface using a mobile robot, wherein the mobile robot comprises a moveable support, a robot arm moveably mounted on said moveable support,

a printhead supported on the robot arm, and an ink supply device connected to the printhead via a fluid line, the method comprising:

positioning the printhead in a predetermined position relative to the three dimensional surface;
determining an orientation and position of the printhead;

5 controlling the printhead to move in order to compensate for vibrational motions and/or positional errors of the support and of the robot arm, based on the measured orientations and positions;

measuring an inflow pressure of the ink directly upstream of the printhead; and

10 controlling the flow of ink from the ink supply device to the printhead depending on the printhead orientation and on the inflow pressure in a manner ensuring that the inflow pressure is above a predetermined lowest ink pressure operating value for operating the printhead.

25. Method according to claim 24, wherein the printhead is a printhead of the recirculation type, and the method further comprises measuring an recirculation pressure of the ink directly downstream of the printhead, and controlling the flow of ink from the ink supply device to the printhead depending on the
15 recirculation pressure in a manner ensuring that the recirculation pressure is below a predetermined highest ink pressure operating value for operating the printhead.

Fig. 1

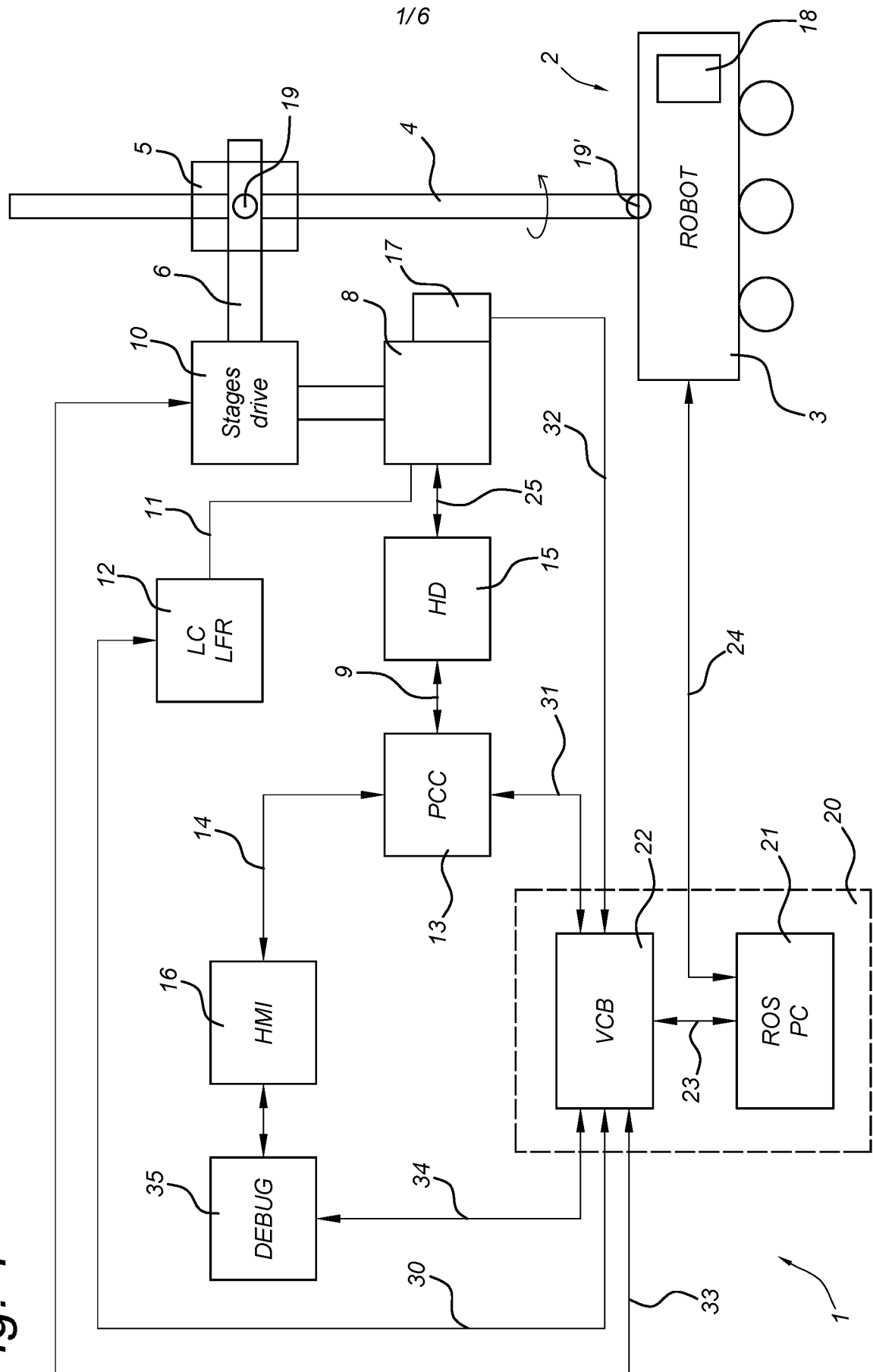


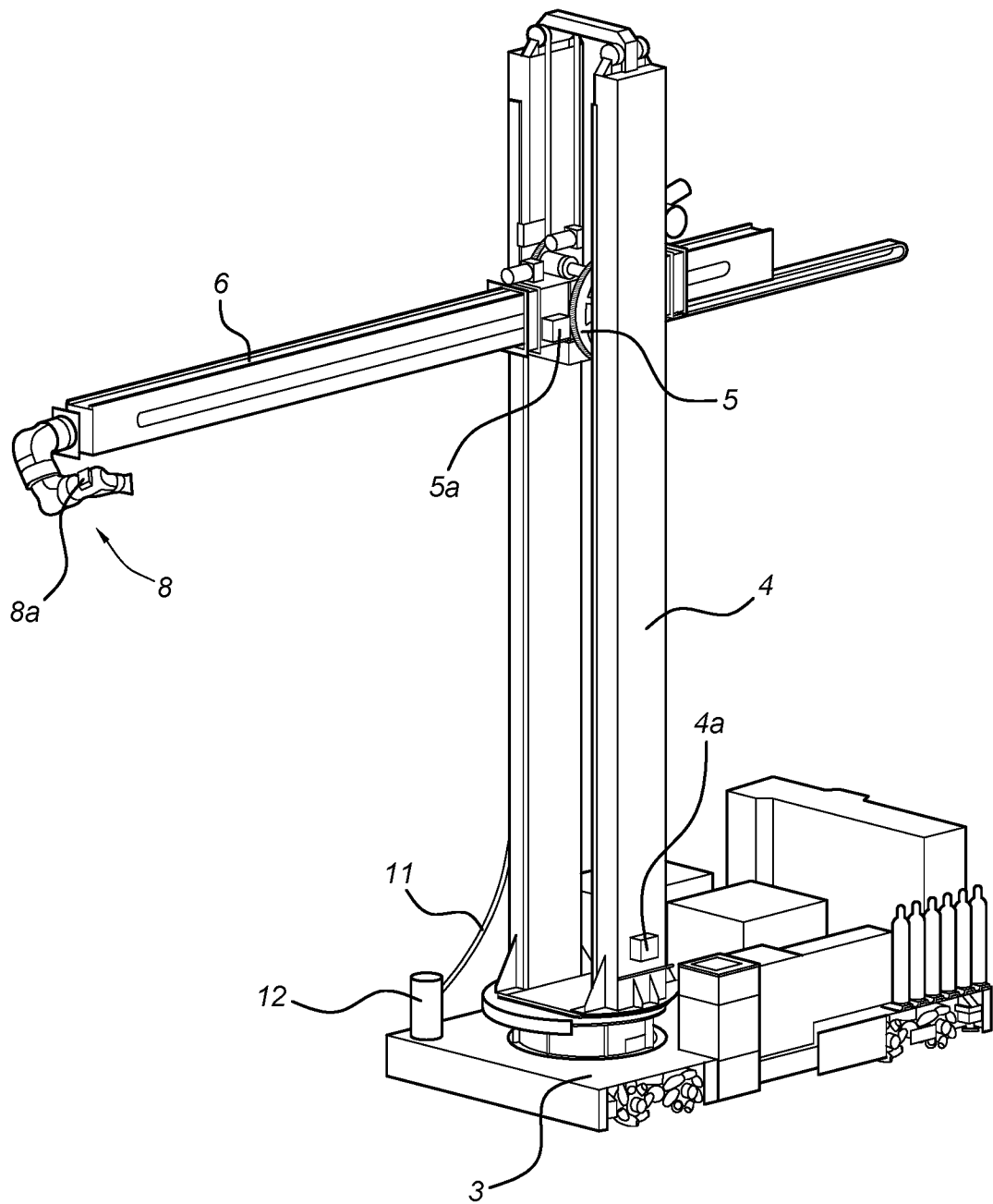
Fig. 2

Fig. 3A

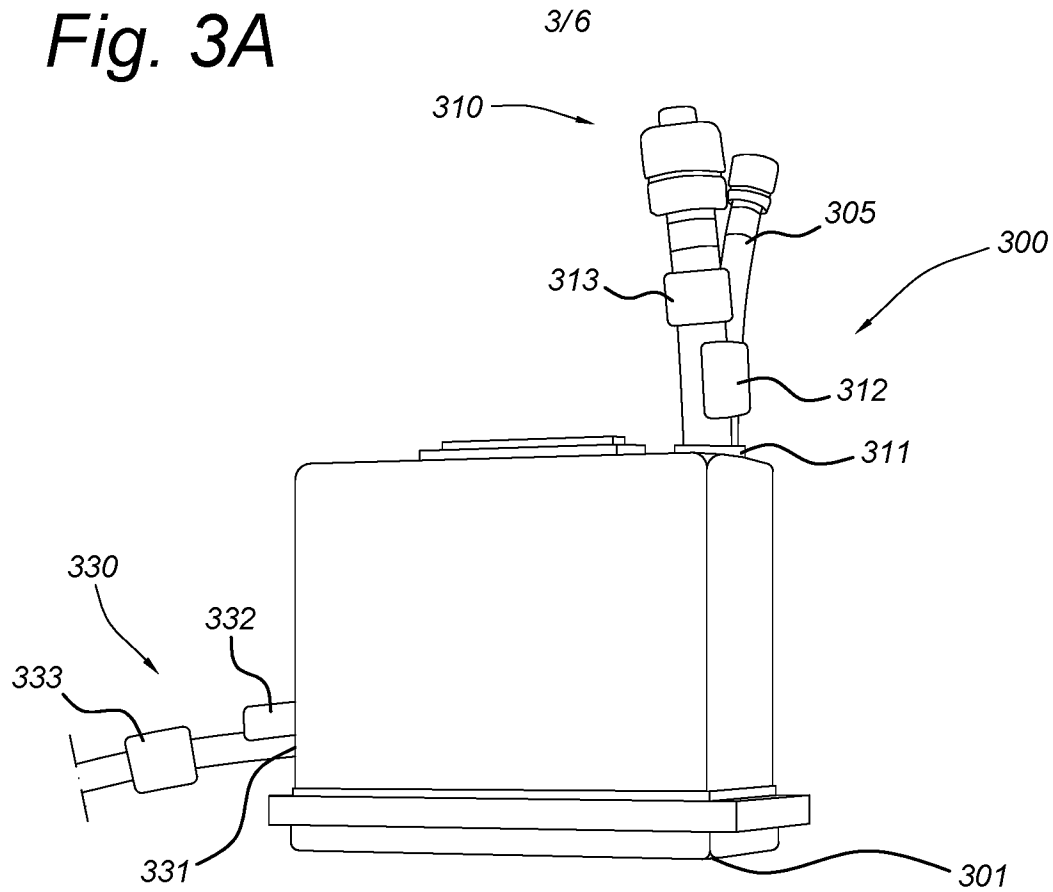
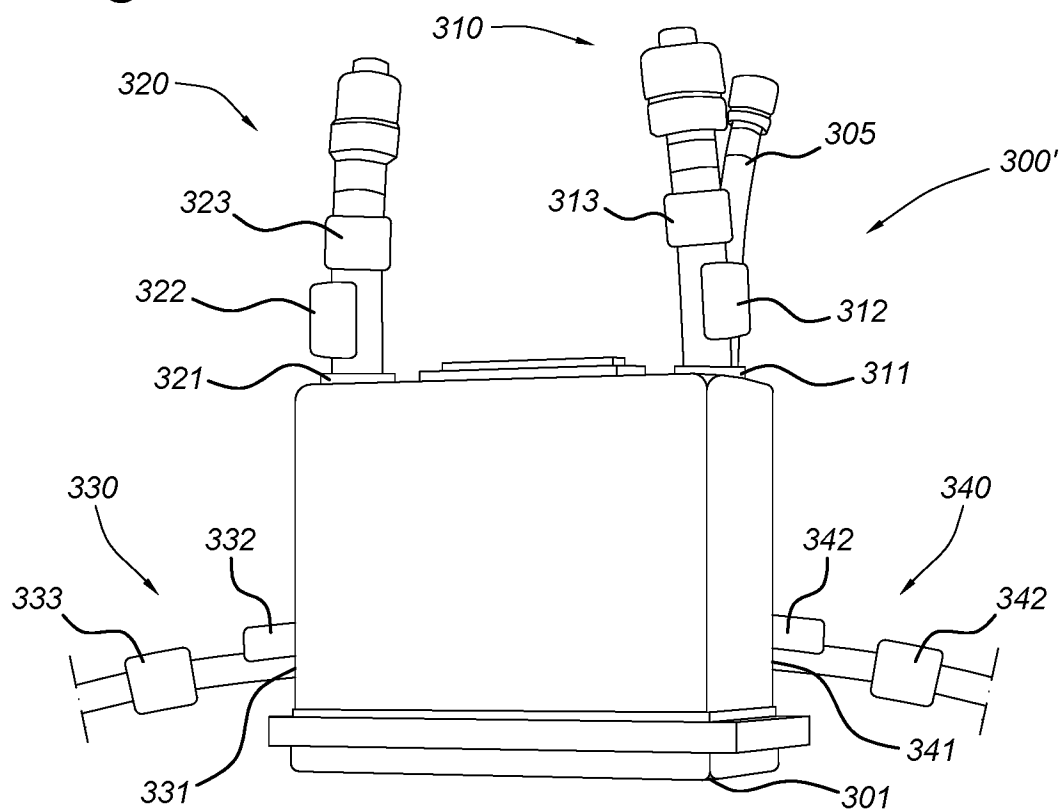
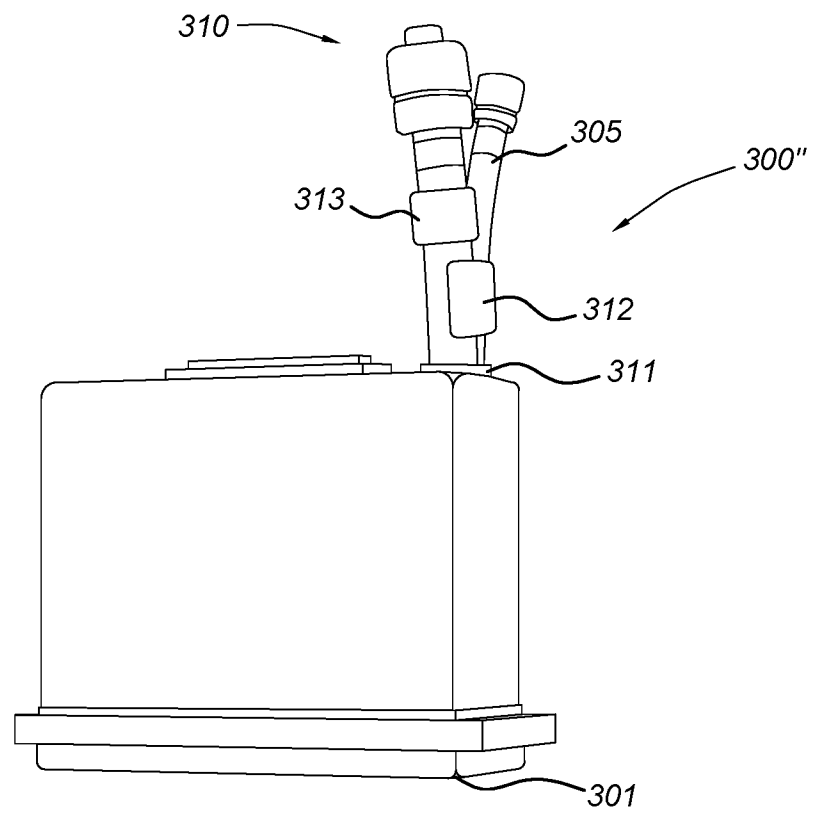
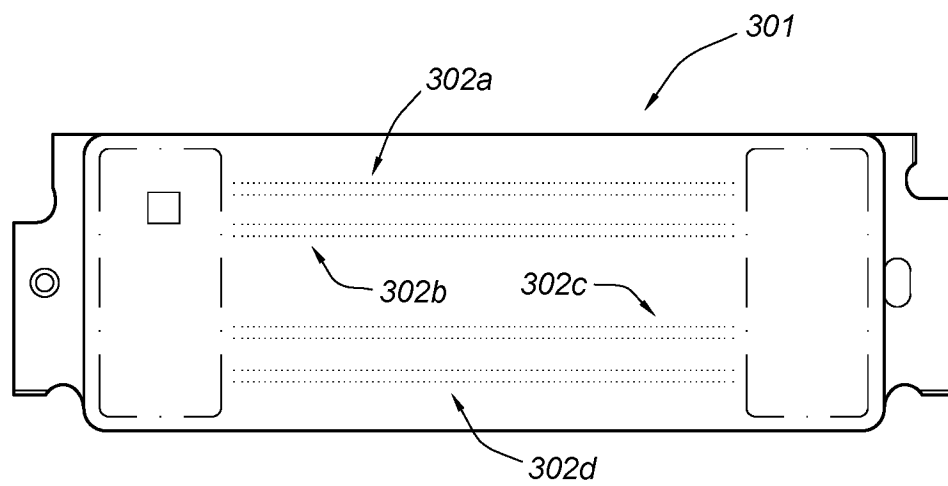


Fig. 3B



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Fig. 3C*Fig. 3D*

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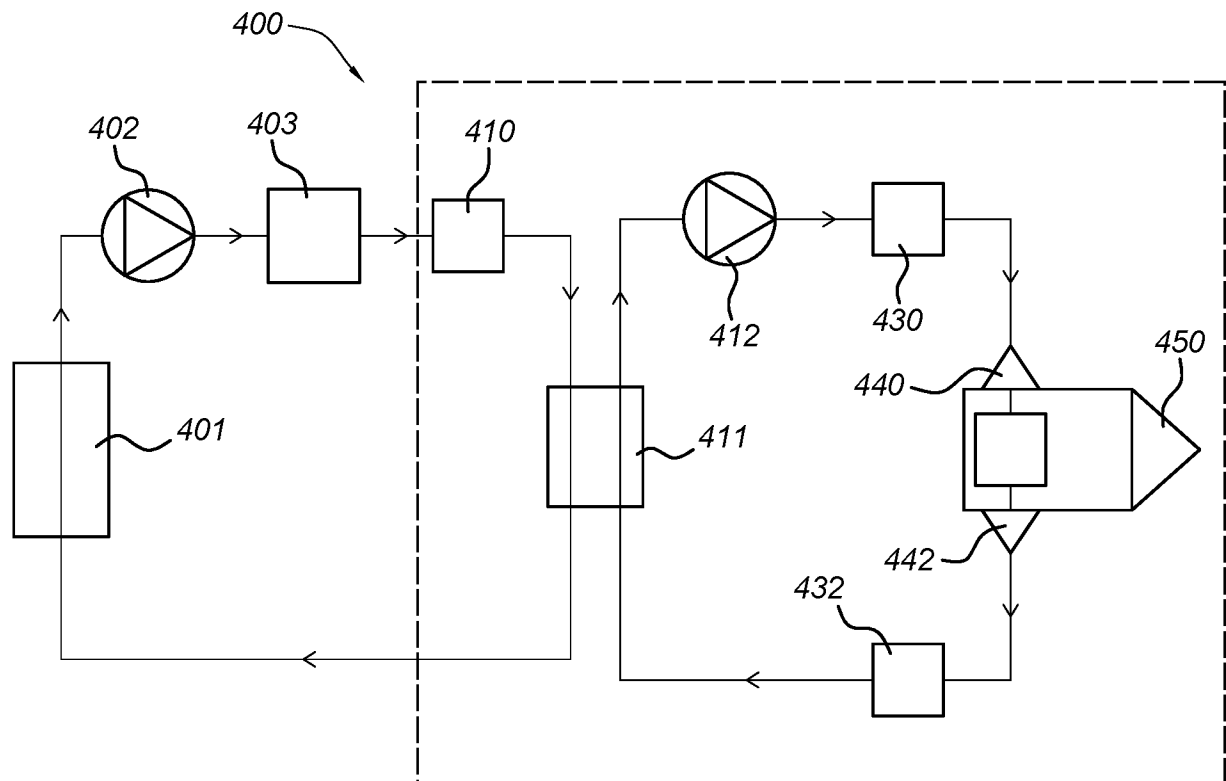
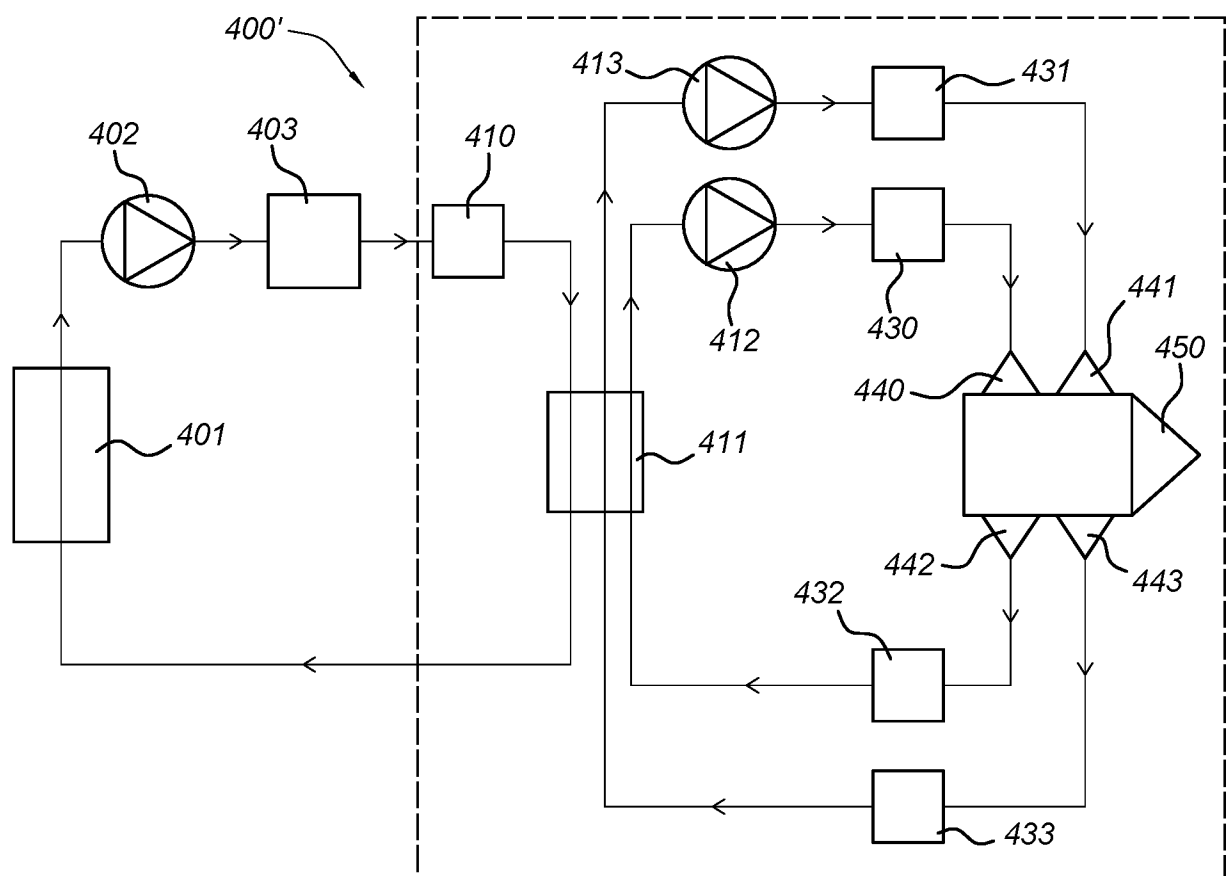
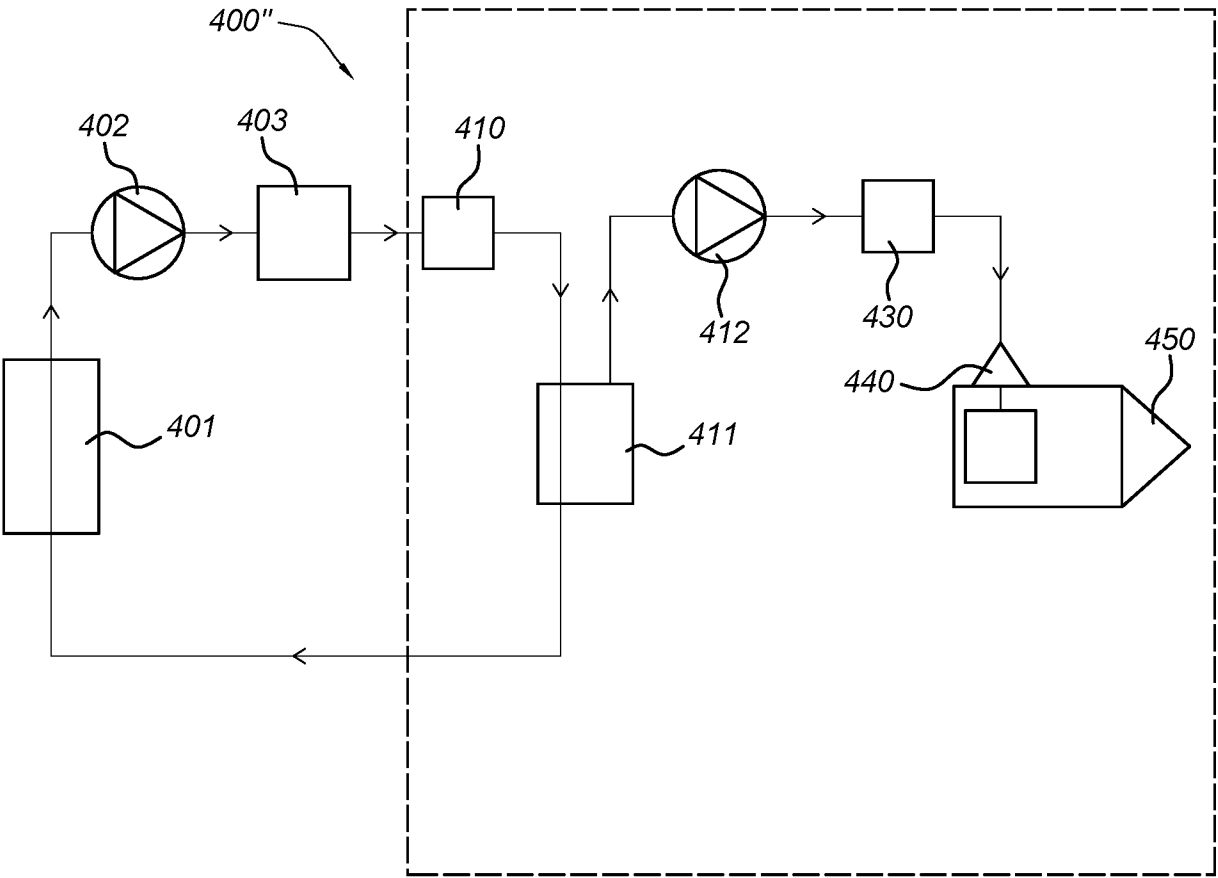
Fig. 4A*Fig. 4B*

Fig. 4C



INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2020/050116

A. CLASSIFICATION OF SUBJECT MATTER

INV. B41J2/18 B41J2/175 B41J3/407 B25J11/00 B05B13/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B41J B25J B65D B05B G05B

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

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Y	paragraph [0003] - paragraph [0030] -----	23,24
X	US 2015/009254 A1 (KAIBA TADASHI [JP] ET AL) 8 January 2015 (2015-01-08)	1,9,12, 13,15, 21,22,24
A	paragraph [0005] - paragraph [0031] -----	10,11
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A	column 3, line 25 - line 57 ----- -/-	1,3-8,20



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No

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