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(54) **Title**: LEARNING SYSTEM FOR PAINTING ROBOTS

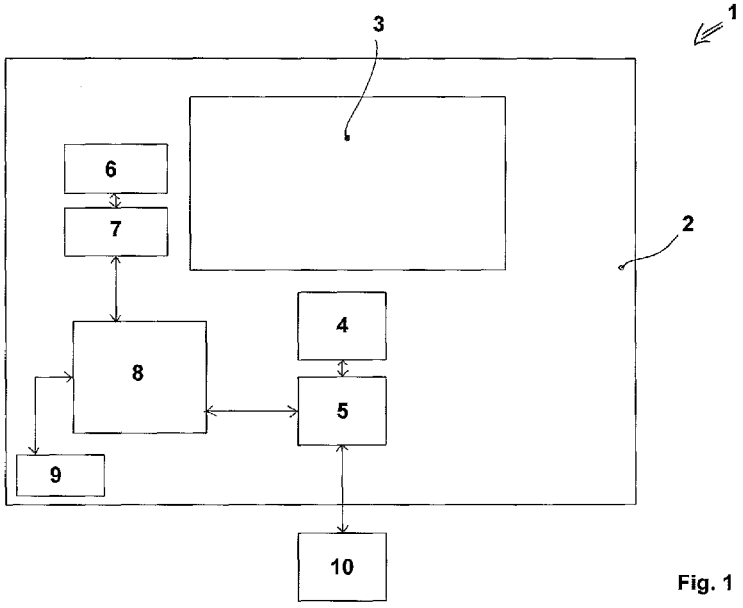

Fig. 1

(57) **Abstract**: The invention concerns a learning system (1) for robots (4) used in processes for painting surfaces in general, comprising a learning station (2), means (3) for supporting the piece to be painted, a device (6) designed to be used or handled manually by an operator to complete at least a first, real or simulated painting cycle on said piece for the robot to learn, an instrument (7) for recording the sequences of coordinates indicating the position and orientation in space of said painting device (6) during said painting cycle for the robot to learn, and a data processing and control unit (8) for processing said recorded sequences of coordinates, designed to communicate with the control panel (5) of a robot (4).

WO 2012/150485 A1

LEARNING SYSTEM FOR PAINTING ROBOTS

DESCRIPTION

The present patent relates to painting processes using anthropomorphic robots and particularly concerns a new learning system for robots used to paint surfaces in general that relies on an emulation-based guide method.

There are known anthropomorphic robots, i.e. machines capable of automatically completing various types of process in a variety of applications.

For them to be able to complete a process, these machines must be suitably taught.

Various methods are used to teach robots, which may be more or less complicated from the operator's point of view. Clearly, once the robot has learned a process, the more this process is repeated, the lower the cost of its training distributed over the parts that are processed will be.

One of the known typical applications for anthropomorphic robots is in painting processes, which consist in the application of paints, adhesives or other such products in liquid or powder form to all kinds of surface.

For instance, there are known processes for painting surfaces in general, on materials such as wood, metal, plastic, as in the case of door and window frames, for instance, or furniture, chairs, tables, etc.

In some cases, however, the operations needed to teach the machines can prove very demanding because the number of like pieces to treat is often rather limited in this type of application.

It is therefore advisable to rely on tools for teaching the movement required of the robot that are speedy for operators to implement and not particularly demanding.

Moreover, for some types of object requiring painting at the known robotised workstations, the trajectories to learn are often very complicated and

consequently demand very long programming times.

The methods currently available for teaching robots at painting stations are as follows.

1. Point-to-point programming: this consists in identifying a discrete number of points along the ideal trajectories that the machine is required to follow and inputting them via the keyboard; then the robot's control unit automatically interpolates between the various points. This is a lengthy and laborious procedure that produces dubious results because it is difficult to identify the ideal points and the trajectories processed by the machines are not always the most appropriate for completing the process.

2. Guiding the robot via the keyboard with the aid of cursors or joysticks and memorising its movements: this is also a laborious method that is difficult to complete and highly inaccurate because it is by no means easy to make the machine follow the ideal trajectories.

3. Guiding the robot directly by means of sensors attached to the robot: the operator takes action on the sensors, which send signals to the robot's control unit, and the latter drives the axes to make the robot's wrist move in the required manner, recording its movement in the process. This guide method is not easy to implement, the trajectories are unnatural and the speed has to be very low for safety reasons.

4. Means for viewing the items to be painted with a software that automatically generates the painting trajectories: these solutions are often used to paint mainly one- or two-dimensional articles, but in the case of three-dimensional objects the complexity and consequent cost of the software would be too great for this solution to be practicable.

5. Operator-guided robots with a self-training capability: these are very lightweight, balanced machines made so that operators can move the whole

structure with ease when the motors are not in operation. This enables them to make the robot simulate the movements needed to complete the painting cycle and memorise them so that they can subsequently repeat them automatically. The drawbacks of this approach lie in the dimensions of the machine, which obviously cannot be particularly large and/or sturdy. The painting movement is also somewhat hampered by comparison with a manual painting action due to the need to move the whole machine by hand. It should be noted, moreover, that robots must be custom-made for this type of application, i.e. generic machines available on the market cannot be used for this purpose.

To overcome the above-listed drawbacks of existing systems, a new type of learning system has been studied and devised for robots used to paint surfaces in general, relying on an emulation-based guide method.

The main object of the present invention consists in using a self-training procedure to speed up the process of teaching one or more robots to paint surfaces in general of any shape and material.

Another object of the present invention is to guarantee a high quality painting result because the robots learn by means of a real or simulated painting cycle completed directly and manually by an operator in the most natural possible way.

Another object of the present invention is to be suitable for training any type and number of painting robots.

Another object of the present invention is to acquire the data concerning the position and orientation of one or more painting guns or devices that can be handled by an operator and consequently memorise any painting cycle in real time.

Another object of the present invention is to memorise painting cycles and subsequently be able either to repeat identical cycles for an indefinite number of

times, or to process them and manage them so as to adapt them to specific needs.

The new learning system with an emulation-based guide method involves the operator using a normal painting device, such as a spray gun, and moving it by hand in the most simple and natural possible way to simulate or actually complete a painting cycle while the robot remotely tracks the work being done and memorises it so that it can repeat it an indefinite number of times.

Said guide method comprises a recorder instrument capable of identifying the sequence of positions occupied by the gun and its orientation, and therefore the movements it completes during the manual painting process, transmitting this information to the control unit of a robot.

Said recorder instrument relies on one or more accelerometric and/or magnetic, and/or optical, and/or radio-frequency sensors or detectors, and/or other devices useful for the purpose, designed to obtain a measurement of the gun's position and orientation in relation to a known triad.

Description of the system

The new learning system comprises:

- a learning station complete with at least one means of support for one or more pieces or objects or surfaces in general to be painted;
- at least one manual painting device or gun, or other device suitable for being handled or used by an operator to complete all or part of one or more real or simulated painting sequences to learn;
- an instrument for recording one or more sequences of coordinates identifying the position and orientation in space of said painting device, comprising for instance at least one sensor attached to said painting device;
- at least one control unit for processing data provided by said recorder, designed to communicate with the control panel for one or more robots suitable for being taught to complete the painting cycle.

Said control unit therefore acquires and processes the sequence of coordinates recorded, converting them into a sequence of painting robot displacements, that it sends to the control panel governing the functions of one or more robots.

The new learning system may or may not be integrated in a painting station, also comprising one or more of said painting robots and any ancillary components, such as a fume extractor booth and a conveyor for carrying the articles to be painted.

In this case, said means for supporting the pieces may be one of the holders or suspended trays installed on an automatic piece conveyor.

The new learning system also preferably comprises at least one switch, or microswitch connected to the trigger of the painting device to record the starting and stopping of the spraying phases.

The new system also preferably comprises at least one portable keyboard for inputting instructions of various kinds for the equipment at the new station.

Said recorder instrument may, for instance, comprise a signal transmitter capable of measuring the position and orientation of the gun, or other devices used in the learning process.

Provision can also be made for said robot control panel to communicate with the automatic conveyor of the parts to be painted as well.

Operation of the system:

1. The operator holds the real or simulated painting device and enables its synchronisation with the robot. At this stage, it is possible to choose whether or not to make the robot move already during the teaching phase.

2. Learning phase: the operator enables the recording to start and completes the simulated or real painting process on a part to be painted. The system conducts a whole set of tests and it notifies the operator if his/her movements go beyond the kinematic capacity of the machine (limits relating to

position, speed, acceleration, curvature, etc) and interrupts the data acquisition process.

3. At the end of the recording phase, the gun is returned to its holster or holder at the painting station and the previously completed painting cycle is memorised in said data processing and control unit.

4. At this point, a cycle can be started immediately to automatically paint the parts, or the previously memorised cycle can be tested and edited. During this phase, for instance, the operator can decide to repeat one or more parts of the cycle, to repaint a portion of a surface, or one side of a piece, to increase or reduce the painting speed, or to vary the distance of the gun from the piece being painted.

5. Once a painting cycle had been memorised, it can be recalled whenever necessary. It is also possible to select the number of pieces to be painted, after which the robot stops automatically.

According to a possible embodiment, the pieces to be painted can be carried by an automatic conveyor (which may consist of suspended trays) to one or more workstations and, when in operation, the robot can be programmed to paint one or more identical pieces on each suspended tray.

Provision can be made for said automatic conveyor to include a motor for automatically rotating the pieces to be painted.

For instance, each suspended tray can contain two or more of the same pieces, in which case only one piece may be painted during the learning phase, while the other can subsequently be painted automatically.

The new learning system can serve an unlimited number of robots.

The painting cycle or program can also be saved in several parts, or "part programs", e.g. one or for each side of an object to be painted.

These memorised part programs can be launched in a sequence decided by the

operator, and/or combined to meet specific needs, e.g. to modify the speed of completion or to save a revised version of the trajectory of one or more of said part programs without having to modify the others.

Fig. 1 shows a layout of the new learning system (1) and how the components are interconnected and communicate with one another.

The new learning system (1) comprises a learning station or cell (2), wherein there are means (3) for supporting one or more pieces or objects, or surfaces in general to be painted, said supporting means (3) preferably being movable in order to rotate the piece, for example manually or automatically.

The new system also comprises at least one device, such as a manual painting gun (6) or other device suitable for being used or handled by an operator, who completes the first simulated or real painting cycle for the robot to learn on at least one piece or part of a piece, completing the process in the most natural possible way.

The new system also comprises an instrument (7) for recording the position and orientation in space of said painting device (6).

Said recorder (7) may, for instance, be of the type with accelerometric and/or magnetic, and/or optical, and/or radio-frequency detectors or other devices, and designed to record measurements of the position and orientation of said painting device (6) in relation to a known triad.

The new system also comprises at least one control unit (8) for processing the data acquired from said recorder (7), also designed to communicate directly or indirectly with at least one control panel (5) serving at least one painting robot (4). Provision can be made for said control panel (5) to control an automatic conveyor (10) for carrying the pieces to be painted as well.

The new learning system also preferably comprises at least one, preferably portable keyboard (9) for inputting instructions of various kinds, said keyboard

(9) being connected to the control unit (8).

The above schematic methods suffice for a person skilled in the art to implement the invention; variations may consequently be introduced in its practical application, without this affecting the substance of the innovative concept.

Thus, with reference to the above description and to the attached drawings, the following claims are advanced.

CLAIMS

1. A learning system (1) for robots (4) used in painting procedures on surfaces in general, **characterised in that** it comprises:

- a learning station or cell (2);
- supporting means (3) for one or more pieces or objects, or surfaces in general to be painted;
- at least one manual painting device (6) installed at said station (2) and designed to be used or handled manually by an operator to complete at least a first real or simulated painting cycle for the robot to learn, on at least one piece or a part of a piece;
- at least one recorder instrument (7) for recording one or more sequences of coordinates of the position and orientation in space of said painting device (6) during said painting cycle for the robot to learn;
- at least one data processing and control unit (8), designed to acquire and process said one or more recorded sequences of coordinates and communicate with at least one control panel (5) serving one or more robots (4) to make the robot repeating all or part of said acquired sequences of coordinates.

2. A learning system (1) for robots (4) according to claim 1, **characterised in that** it comprises one or more of said painting robots (4) with at least one corresponding control panel (5), wherein one or more of said robots (4) also repeat said sequences of acquired coordinates in real time, during said learning stage, simultaneously with the movement of said painting device (6).

3. A learning system (1) for robots (4) according to claims 1, 2, **characterised in that**, during said first painting cycle for the robot to learn, said control unit (8) checks the compatibility of said acquired sequences of coordinates with respect to the kinematic and dynamic capacities of said painting robots (4).

4. A learning system (1) for robots (4) according to claims 1, 2, 3, **characterised in that** said control unit (8) saves said one or more sequences of coordinates in one or more parts, and wherein each part may be separately processed, repeated by said robots (4), or modified separately from the others.

5. A learning system (1) for robots (4) according to claims 1, 2, 3, 4, **characterised in that** said piece-supporting means (3) are manually or automatically movable.

6. A learning system (1) for robots (4) according to previous claims, **characterised in that** said recorder instrument (7) is based on accelerometric sensors or detectors and/or on magnetic sensors or detectors, and/or on optical sensors or detectors, and/or on radio-frequency sensors or detectors, and/or on other recording devices.

7. A learning system (1) for robots (4) according to previous claims, **characterised in that** it comprises at least one, preferably portable keyboard (9) for inputting instructions of various kinds, said keyboard (9) being connected to said control unit (8).

8. A learning system (1) for robots (4) according to previous claims, **characterised in that** said painting device (6) comprises a switch connected to said control unit (8), to enable the starting and stopping of the spraying phase to be recorded.

9. A learning system (1) for robots (4) according to previous claims, **characterised in that** said control panel (5) for said one or more robots (4) is connected to at least one external automatic conveyor (10) for carrying the pieces to be painted, said conveyor (10) carrying one or more suspended trays to one or more workstations.

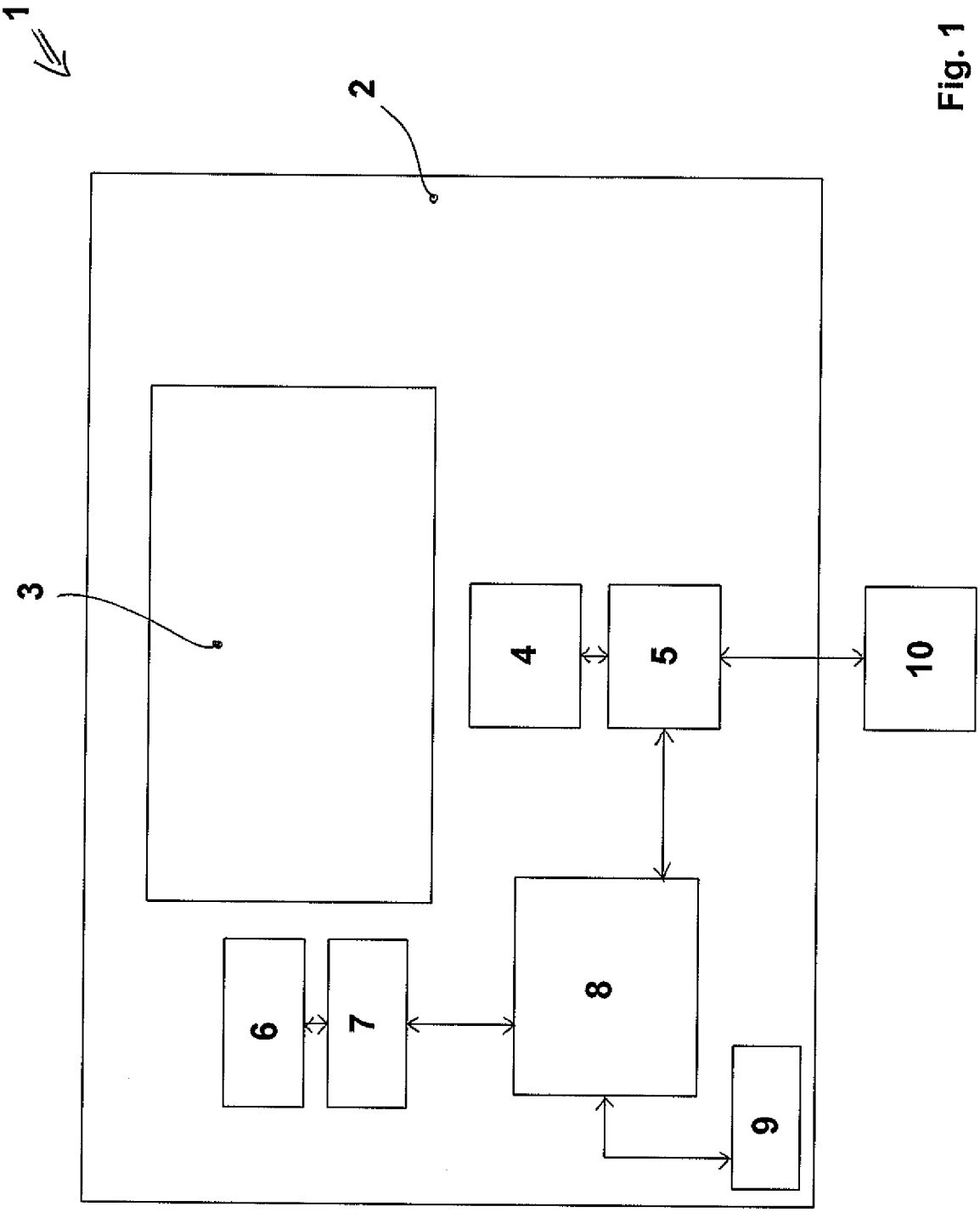

Fig. 1

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2011/052008

A. CLASSIFICATION OF SUBJECT MATTER
INV. G05B19/427 B25J9/16
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)
G05B B25J

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 practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2011/039542 A1 (WELDING INSITUTE [GB]; MELTON GEOFFREY BERNARD [GB]; PIKE SIMON GEOFFR) 7 April 2011 (2011-04-07) page 1 - page 20; figures 5,6	1-9
X	WO 2005/060338 A2 (ABB RESEARCH LTD [CH]; BRODTKORB DAGFIN [NO]; PRYTZ GUNNAR [NO]) 7 July 2005 (2005-07-07) page 5, line 29 - page 11, line 32; figures 1-5	1-9
X	US 2005/149231 A1 (PRETLOVE JOHN [NO] ET AL) 7 July 2005 (2005-07-07) paragraph [0001] - paragraph [0037]; figure 1	1-9

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 September 2011	06/10/2011

Name and mailing address of the ISA/	Authorized officer
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 950 559 A1 (ARTISTIC ROBOT EVENT [FR]) 1 April 2011 (2011-04-01) page 1 - page 15; figure 1	1-9
X	HOLGER FRIEDRICH ET AL: "Interactive Robot Programming Based on Human Demonstration and Advice", 1 January 2007 (2007-01-01), SENSOR BASED INTELLIGENT ROBOTS LECTURE NOTES IN COMPUTER SCIENCE;LECTURE NOTES IN ARTIFICIAL INTELLIG ENCE;LNCS, SPRINGER, BERLIN, DE, PAGE(S) 96 - 119, XP019048470, ISBN: 978-3-540-66933-3 the whole document	1-9
A	JENS KOBER ET AL: "Imitation and Reinforcement Learning", IEEE ROBOTICS & AUTOMATION MAGAZINE, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 17, no. 2, 1 June 2010 (2010-06-01), pages 55-62, XP011310836, ISSN: 1070-9932 page 55	1-9

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2011/052008

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WO 2011039542 A1	07-04-2011	NONE	
WO 2005060338 A2	07-07-2005	NONE	
US 2005149231 A1	07-07-2005	NONE	
FR 2950559 A1	01-04-2011	WO 2011039429 A1	07-04-2011