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(54) Title of the Invention: **Ambulatory robot system**
Abstract Title: **Ambulatory robot system**

(57) An ambulatory robot system 10 comprises two robot units 11, 12 each provided with attaching means 14 for selectably attaching and detaching the respective unit 11, 12 from a surface (15a, 15b fig. 4A), a coupling linkage 13 composed of articulated limbs 16, 17 coupling the units 11, 12 together to be relatively movable for varying their positional relationship and drive means 19 for displacing the coupling linkage 13 to produce the relative movement when one unit 11, 12 is detached from the surface (15a, 15b fig. 4A) and the other unit remains attached to the surface (15a, 15b fig. 4A), the detached unit 11, 12 being rotatable relative to the attached unit 11, 12. The units 11, 12 may comprise two relatively rotatable parts 11a, 11b and 12a, 12b. One end of the coupling linkage 13 may be provided with a functional component 20, the end being capable of being uncoupled from one of the units 11, 12. The attaching means 14 may be a plug or socket, magnetic fixing means or suction fixing means. The units 11, 12 may include traction means 21 move over a surface.

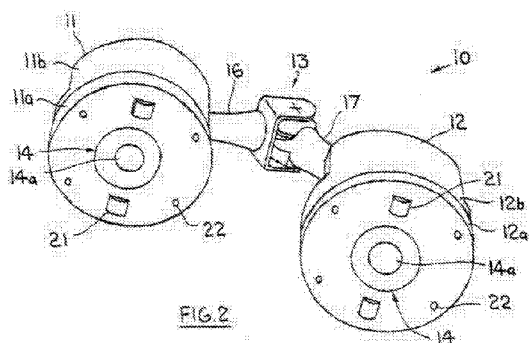


FIG. 2

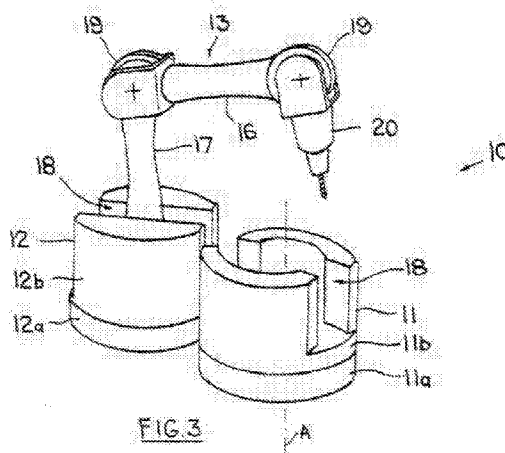
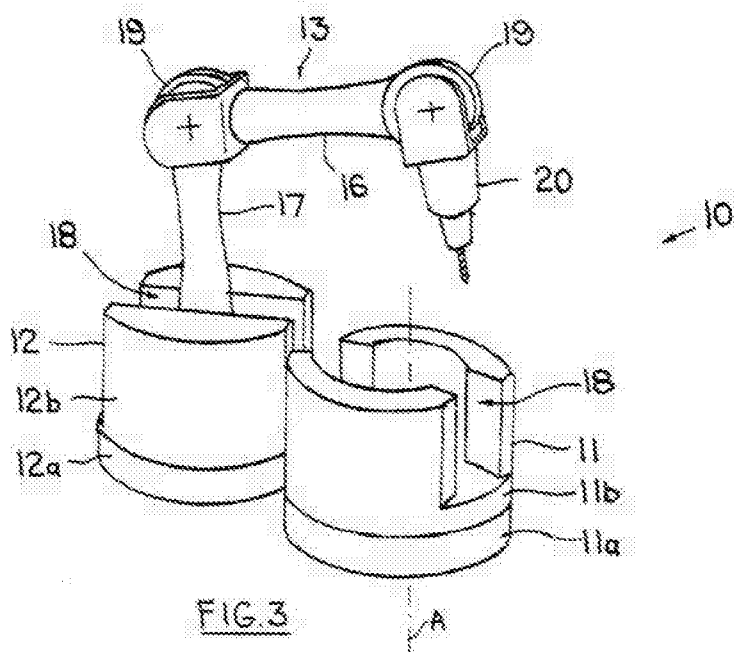
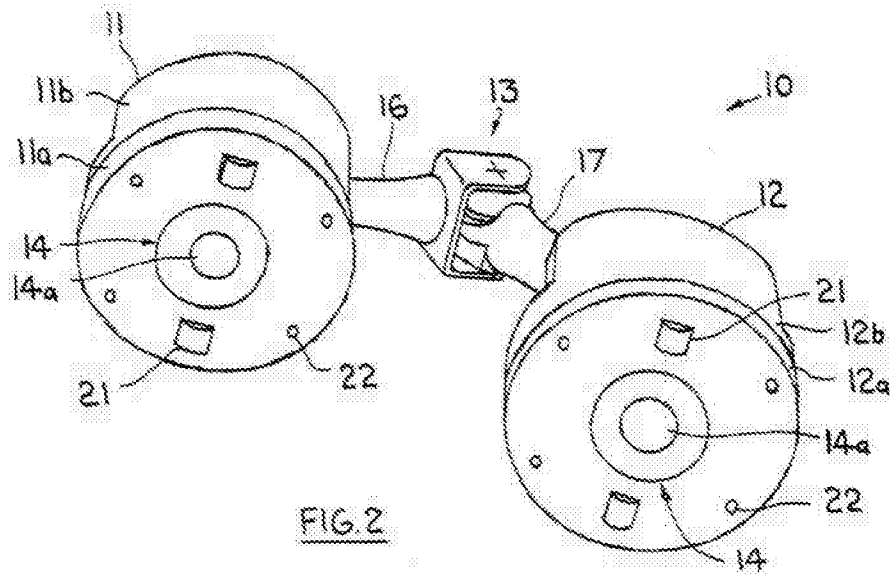
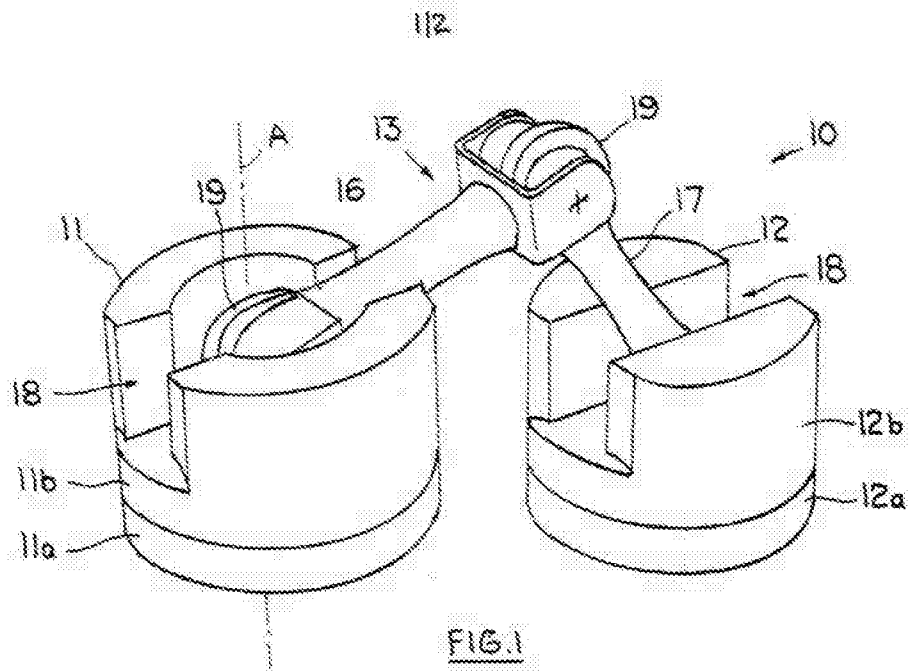


FIG. 3



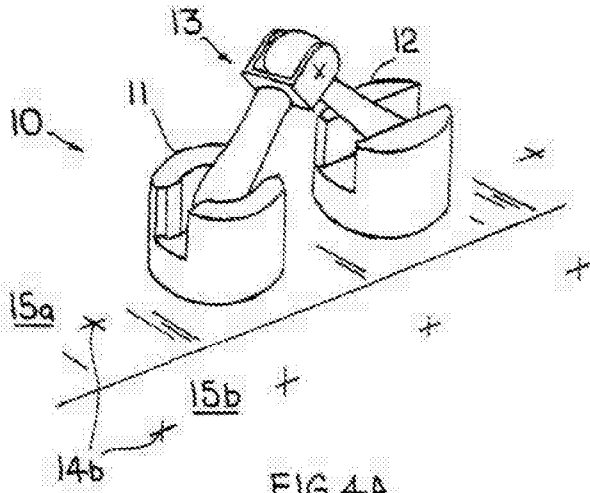


FIG. 4A

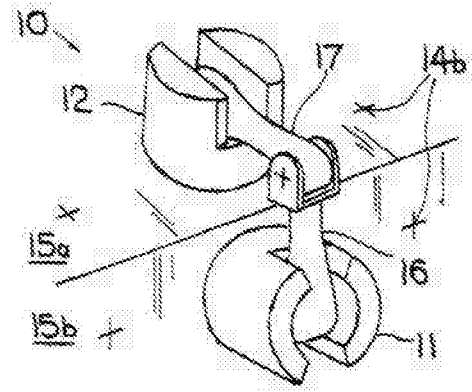


FIG. 4B

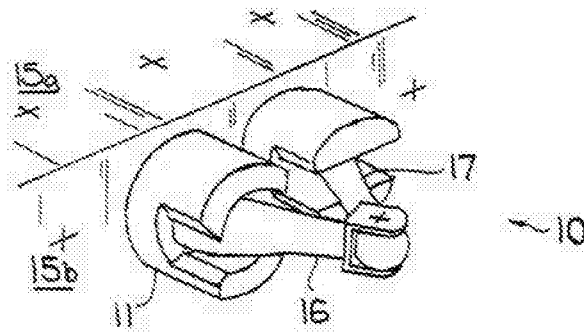


FIG. 4C

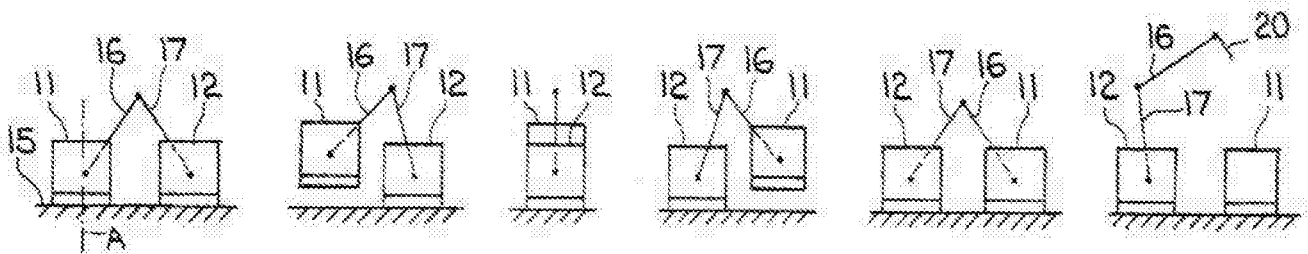


FIG. 5A

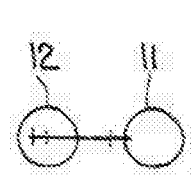
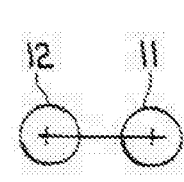
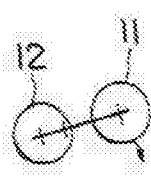
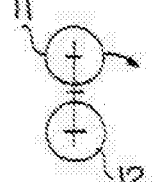
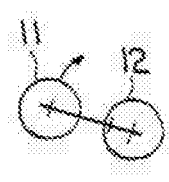
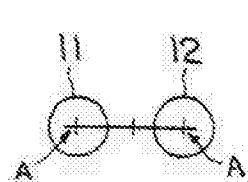
FIG. 5B

FIG. 5C

FIG. 5D

FIG. 5E

FIG. 5F



AMBULATORY ROBOT SYSTEM

The present invention relates to an ambulatory robot system, especially a system with robot units able to travel in a walking motion along a surface or surfaces.

Robot systems exist in many forms and, most commonly, as robots or manipulators in stationary locations in production, assembly or packaging plants or as mobile robots capable of autonomous travel and able to perform a variety of functions, such as inspection, surveillance, repair, cleaning and specific remotely controlled operations. Mobile robots are usually wheeled or tracked vehicles which may be able to negotiate, including climbing over, obstacles and which move freely over surfaces without adhesion to those surfaces. Robots of this kind are suitable for a wide range of tasks, but are not intended or optimised for performance of repetitive actions on, for example, a substrate supporting the robot. Such actions include, by way of example, welding, cutting, creation of fastening points, destruction of fastening points, drilling, surface treatment and a multitude of other operations to be undertaken progressively along a surface or at adjacent surfaces or areas. Multi-legged, especially bipedal and quadrupedal, robots able to walk in a manner mimicking two-legged or four-legged animals have existed for some time and are generally characterised by bulky and complicated configurations with limited or negligible suitability for utility purposes of the kind mentioned. More recent developments include multi-legged, for example hexapedal, ambulatory micro-robots which are designed on a quasi-insect basis for small-scale activities and which execute autonomous locomotion by free motion, in a walking gait, along surfaces. All these mobile robots have the form of a body with depending articulated actuators functioning as legs, but none of the robots of the mentioned kinds constitutes a task-dedicated instrument appropriate for repetitive actions requiring progressive ambulatory motion between and pause at discrete locations for performance of duties.

A quite different approach to robot mobility is represented by modular robotic systems with a self-configuring capability, such a system being formed by interconnected modules able to change their connectivity and consequently the form of the robot embodied by the system. In this case, motion can be achieved by variation of the module connections to provide extension in a chosen direction, in effect growth of the robot in a specific dimension to enable sliding motion along a surface, or by temporary creation of legs for some form of ambulatory motion and even separation into dispersed groups of modules.

Such robotic systems are not ambulatory systems as such, even if transiently endowed with an ambulatory capability through a specific variation in morphology, and the constructional and control complication of modular systems of this kind is not compatible with simple and economic performance of repetitive industrial or commercial tasks.

Conversely, a "walking robot" is described in US 2018/0099710, assignee The Boeing Company ('Boeing'), in which two robot units coupled by a divided and articulated coupling link or "arm" are selectively attachable by suction or mechanically to a surface to be processed by the robot, for example an aircraft fuselage skin to be drilled or riveted. The attached units are detachable in succession from the surface so that when detached they can be moved, by way of folding and unfolding of the coupling arm at articulation points, to execute steps across the surface. The steps are referred to as an "inchworm" motion, in effect a dragging gait along a line lying in a single vertical plane, or "a stride similar to an adult human" or "a side wobble similar to a human toddler". The drawings of US 2018/0099710 appear to show ambulation by an inchworm motion or by striding, for which purpose the two halves of the coupling arm apparently lie in parallel planes and are pivotable about a common intermediate axis, as evidenced by the drawing figures showing one arm half partly behind the other in partially folded states of the arm. The wobble motion is not further described or illustrated; there is no teaching relative to realisation of this motion or of other unspecified "desirable" forms of walking. Similarly, although joints in the articulated arm are stated to allow the ends of the arms to move within a plurality of axes there is no further explanation of movement capabilities these joints may bestow and the related drawing, which shows partly overlapping arm halves, implies that the axes are those which allow the arm to fold, unfold and pivot relative to the robot units in parallel planes.

Although the Boeing robot embodies a capability of ambulation, the mentioned forms of motion and the illustrated coupling arm of the units indicate that the ambulation is confined to a path lying in a single plane or parallel planes. Accordingly, the freedom of movement of the robot when walking is subject to a significant constraint and the utility of the robot, when one of the units is detached and equipped with a tool to perform tasks, is correspondingly limited.

It is accordingly the principal object of the present invention to provide a robot system with an improved capability of ambulation between directionally diverse locations so as to be

positionable for performance of tasks at or in the region of those locations and also with an enhanced range of work operation in phases between ambulation.

Other objects and advantages of the invention will be apparent from the following description.

According to the present invention there is provided an ambulatory robot system comprising two robot units each provided with attaching means for use in selectably attaching the respective unit to and detaching that unit from a surface, coupling means coupling the units together to be relatively movable for varying their positional relationship and drive means for displacing the coupling means to produce the relative movement when either one of the units is detached from a surface while the respective other unit remains attached to a surface, the detached robot unit being rotatable relative to the attached unit to allow the detached unit to travel on a path around an axis of the attached unit.

Unlike ambulatory robots usual in the prior art, a robot system embodying the present invention is based on a bipedal concept in which ambulation along a surface can be achieved by alternate adhesion of each robot unit to and release of that unit from the surface and by drive of the coupling means to appropriately move the released or detached unit relative to the still-adhered or still-attached unit, the repositioned unit then being re-attachable. In this way the units can be moved in alternation to walk - in a somewhat 'plodding' motion by analogy with human ambulation, optionally inclusive of relative rotation of the units - along a surface and in addition, depending on the movement capabilities of the coupling means, can transfer between surfaces. Either or each unit or the coupling means itself is in a position, when the system is static, of performing a pre-designated task on the surface or in the environment of the surface and can be suitably equipped for that purpose. Such a system is optimised for performance of repetitive work at or around discrete locations along a supporting substrate and can be of relatively simple and economic construction, particularly by comparison with other ambulatory robots achieving ambulation by complicated surface-engaging actuators. Although the concept of the robot system of the present invention is bipedal, the concept is the inverse of prior art humanoid systems based on a body or structure with actuator-operated depending legs: in the present invention the core elements are the robot units, which equate with feet, the coupling means being merely a linkage in a drive train. In stark contrast to most bipedal

prior art robots, ambulation is achieved by alternating anchorage of the robot units or feet to the surface or surfaces being negotiated. Further, by contrast to the Boeing robot, the specific relative rotation capability of the robot system of the present invention allows a change in direction of ambulation, which can be designed to be within a range of 360 degrees, and in a static state of one of the units also allows, separately from the requirements of ambulation, repositioning of the other unit for task performance within a work range around the static unit.

In one ambulation procedure the coupling means is displaceable by the drive means to raise, lower and tilt the detached robot unit relative to the attached unit and to move the detached unit towards and away from the attached unit, which simulates a walking action capability of a bipedal animal and allows clearance of obstacles and adjustment to different surface levels or angles encountered between raising and lowering. This form of travel of the robot units is quite distinct from, for example, a relative sliding or rolling motion and affords greater scope for transfer of the units between relatively angled surfaces and for bridging over gaps or voids. In simpler forms of ambulatory motion suitable for progression along a rectilinear path the coupling means could be driven by the drive means to, for example, cause the detached unit to simply swing over the attached unit from one side to the other without change in the orientation of the two units or cause the detached unit to move towards the attached unit and, after re-attaching the just-moved unit, detaching the formerly attached unit and moving it away, thus producing a shuffling motion along a straight path. However, a capability of relative rotation of the units about the stated axis of the attached unit, which may be a function of the articulation axes present within the coupling means and/or present at the connections of the coupling means with the units, permits relative displacement of the units in a three-dimensional rather than merely two-dimensional spectrum. A particularly advantageous realisation of a three-dimensional displacement capability of the units in conjunction with a relatively simple construction of the coupling means with articulation limited to a single plane, thus without resort to universal joints or similar, can be achieved if at least one of the robot units comprises two relatively rotatable parts, the attaching means of that robot unit being provided on one of those parts and the coupling means being connected with the other part. In that case, the relative rotation of the units can be achieved simply by relative rotation of the two parts of the unit of two-part construction. In practice, it is rational for both units to be of such a two-part construction. Symmetry and an optimal space-saving design may be realised if the two relatively rotatable parts are substantially cylindrical, but

there is otherwise no constraint on the volumetric form of the two robot units and their parts.

With respect to the relative rotation of the two robot units the travel path of the attached unit around the stated axis of the attached unit is preferably a curved path in two or three dimensions, for example at least part of a circle or an ellipse. The path can also be a parabola or any other path capable of generation by travel of the detached unit about the axis of the attached unit optionally in conjunction with movement, produced by coupling means displacement of the detached unit towards and/or away from the attached unit. In three-dimensional form the path may define, for example, a helically ascending locus and a helically descending locus.

In a system with a basic ambulatory capability the coupling means can be displaceable by the drive means to move the robot units in succession along a substantially planar surface, so as to walk along a predefined linear track in a single plane. Such a capability may be all that is needed when tasks have to be performed at or around locations along, for example, a rectilinear path. However, in a system with enhanced capability the coupling means can be displaceable by the drive means to move the robot units individually between and along two relatively angled surfaces, in which case either or both of the units can rely on its surface attachment to resist dislocation by gravitational force. Specifically, the coupling means can be displaceable by the drive means to move the robot units individually between and along two mutually perpendicular surfaces, which can be respectively horizontal and vertical, in which case a maximum dislocating gravitational force will act on one of the units both during movement to and after arrival at the vertical surface. This force can be readily resisted simply by ensuring a sufficient strength of attachment of the units to the surfaces and sufficient power of the drive means displacing the coupling means, in conjunction with appropriate calculation of the weights of the units. Subject to these basic and logical mathematical considerations, the robot system can have the capability of walking along and between relatively angled surfaces up to the extreme of orientation of one of the surfaces in a vertical or even beyond-vertical plane.

The coupling means can be provided in various forms, but in a particularly simple and economic, but effective, embodiment it can comprise a plurality of limbs articulated to each other and to the robot units, in which case the drive means can be operable to vary the orientations of the limbs relative to one another and the robot units. In a basic construction

the limbs can comprise two limbs each connected at one end thereof to the respective other limb and at the other end thereof to a respective one of the robot units. The drive means can act on the limbs at their points of connection, particularly a point of connection with at least one of the robot units, but preferably also at the point of limb interconnection so as to vary the angles of the limbs relative to one another and to the robot units in simulation of the motions occurring in the ankle and knee joints of bipedal and quadrupedal animals during walking. The transmission of movement from the drive means to the limbs of the coupling means can be simplified if the limbs are articulated to be movable relative to one another and to the robot units simply in a single plane, in which case three-dimensional movement of the robot units relative to one another can be achieved by way of, for example, the afore-mentioned multi-part construction of a robot unit to incorporate a relative rotation capability of the unit parts. However, subject to the penalty of a greater degree of articulation and drive complexity it remains possible for the limbs to be articulated in such a way as to be movable relative to one another and to the robot units in multiple planes. In either case it is advantageous to configure the points of interconnection of the limbs and robot units so that the limbs are engaged in recesses in the robot units and articulated to the robot units within the recesses. The walls of such a recess provide secure support for an axle or other articulation component, while the recess itself and outlying regions can provide accommodation for drive means components providing relative displacement of a limb and robot unit. Provision of such a recess also allows articulation of a limb to a robot unit at the bottom of the recess so as to be close to an intended base of the unit, in order to optimise stability and, importantly, to accommodate the configuration of the limbs - without giving rise to an excessive limb length - necessary in the case of positioning of the two robot units respectively on two relatively angled, especially at right angles, surfaces. Further, the range of relative pivotation of a limb and robot unit can be enhanced by allowing entry of the former into a recess, particularly a slot-like recess, of the latter, whereby the articulated limbs can be extended to be substantially rectilinear.

In an alternative embodiment, the coupling means can comprise a single flexible shaft and the drive means can be operable to vary the shape of the shaft in the direction of a shaft axis thereof. This can be achieved by, for example, embedding a suitable actuator in the shaft.

The utility of the ambulatory robot system may be significantly increased by a configuration

in which the coupling means is uncouplable from and recouplable to at least one of the robot units, an action which is preferably performed while both robot units are attached to a surface or surfaces. The coupling means in such an uncoupled state is then available to execute functions; if the coupling means is formed by articulated limbs as proposed in the foregoing, the coupling means can replicate the extension and retraction motions of a cantilever jib arm and can be moved to desired work locations reachable from the anchored robot unit to which the coupling means remains connected. Consequently, it is then advantageous if the coupling means is provided with a functional component at an end thereof uncouplable from and recouplable to the at least one of the robot units, for example a tool holder for general purpose tools or another component intended for a specific task, such as a laser welding head, an inserting or extracting device or any other desired implement.

In one preferred embodiment of the invention the attaching means of each robot unit comprises mechanical fixing means, which represents a method of ensuring optimum retention of the unit to a surface to which it is to be attached, particularly so as to resist separation due to gravitational force or due to reaction forces arising from task performance. In that case, the mechanical fixing means can be constructed for interlocking with co-operating fixing means at a surface to which the respective robot unit is to be attached. The surface attachment of the robot unit is then subject to the consideration that the surface itself has to be appropriately configured. This may nevertheless be necessary when the robot system weight and the forces arising during operation, especially when vertical surfaces are involved in robot unit attachment, are such that there is no viable alternative to mechanical fixing. The mechanical fixing means at the robot unit can be a plug or socket, either of which can plug into or onto a mating component at the surface, in particular individual ones of a series of such components. The fixing means can also be, for example, a combination male and female coupling system with recesses in each partner, i.e. robot unit and substrate, and extendible/retractable dogs again at each partner and engageable in the recesses of the respective other partner, in which case the dogs can be releasably locked in the recesses by, for example rotation of a carrier of the dogs.

In an alternative embodiment, the attaching means of each robot unit can comprise magnetic fixing means to allow attachment to a surface by magnetic attraction, which allows the possibility of attaching the units without requiring adaptation of the surface or of

a substrate having the surface. Accordingly, the magnetic fixing means may comprise, for example, an electromagnetic fixing device for generating a magnetic field for attraction to a ferromagnetic surface, such a device being electrically switchable on and off for attaching and then releasing the respective robot unit. It is also conceivable to provide such a device at the substrate with the surface, in which case the magnetic fixing means at the robot unit can be formed simply by an area of ferromagnetic material. In a further alternative to mechanical fixing means, the attaching means of each robot unit can instead comprise suction fixing means so that adhesion to a surface can be achieved simply by sub-atmospheric pressure at an appropriate level. Such suction fixing means preferably comprises a suction generating device present in each robot unit. Alternatively, it is conceivable to provide a suction generating device at the substrate with the surface, the suction fixing means at the robot unit then being a suitably formed, for example planar, area assigned to retention by applied sub-atmospheric pressure.

In order to ensure optimum autonomy of the robot units the system preferably comprises an on-board power source for supplying the drive means with operating power, in which case the source can be conveniently provided at either of the robot units, but preferably at both if each robot unit has an own on-board power source, each unit can operate entirely autonomously. Such a power source may be a battery, especially a remotely rechargeable battery, or an accumulator capable of storing power derived from a remote supply. Additionally or alternatively, the system can comprise power pick-up means for acquisition of operating power for the drive means from a power source associated with the surface or surfaces to which the robot units are to be attached. Although adaptation of the substrate with the surface is then required, a greater level of power, including mains power or pneumatic or hydraulic power, may be able to be provided to achieve an increased drive output force of the drive means, particularly in the case of heavier robot units or units carrying heavier tools or other functional components.

Apart from the ambulatory capability of the robot system, additional locomotion for different circumstances of system movement may be realised if each of the robot units comprises traction means for applying traction to a surface, when the respective robot unit is detached therefrom, to move the detached robot unit over the surface. The traction means, for example rotationally drivable rollers, wheels or tracks, can be utilised when it is desired to move the system more quickly over a substantially horizontal surface for rapid travel to more distant or spaced-apart work locations. In that connection, it may be

advantageous if the coupling means is uncouplable from one of the robot units to allow either or each of the robot units, when detached from a surface, to move over the surface independently of the respective other robot unit in which case each robot will require not only an own drive motor, but also an own power source. Each robot unit is then capable of independent movement in the manner of an autonomous individual robot, but may remain capable of attachment to the surface along which it has independently travelled and, subject to equipping in an appropriate manner, also capable of performing a task at or around the zone of attachment. To that extent, the traction means can impart to the robot system an additional functionality similar to that of a modular system in which a module is separable from and reconnectible with another module, the robot units here representing the modules.

An embodiment of the present invention will now be more particularly described by way of example and with reference to the accompanying drawings, in which:

- Fig. 1 is a schematic perspective view of an ambulatory robot system embodying the invention;
- Fig. 2 is a schematic perspective view of the system of Fig. 1 from an underside of the system;
- Fig. 3 is a schematic perspective view, from a different direction, of the system of Fig. 1 in an exemplifying work configuration;
- Figs. 4A to 4C are diagrams showing the system in use on relatively angled surfaces; and
- Figs. 5A to 5F are diagrams showing, in purely diagrammatic form, phases of ambulation of the system along surfaces.

Referring now to the drawings, there is shown in Figs. 1 to 3 an ambulatory robot system 10 comprising two closely similar or optionally substantially identical robot units 11 and 12, a coupling linkage 13 coupling the units together to be relatively movable in order to vary their positional relationship and drive means for displacing the coupling linkage to produce movement of the units in a selected walking motion as described in more detail further

below. The robot system is intended particularly for performance of tasks at discrete locations to which the units can travel, such tasks including, but not being limited to, production, repair, maintenance and other activities involving execution of work under remote control or on the basis of pre-programmed autonomy.

Each robot unit 11 and 12 is of light alloy construction and has a substantially cylindrical form with respect to a reference axis A of the unit, but can be of any suitable shape depending on requirements. The axes A of the two units, whether or not the units are cylindrical, lie in a common plane. Further, each unit 11 and 12 is composed of two parts, specifically a base 11a or 12a and a head 11b or 12b, which are relatively rotatable about the axis A of the respective unit. Relative rotation of the two parts is provided by a rotary drive unit (not visible), such as an electric motor, drive pinion and driven ring gear, integrated in the respective unit. The bases 11a and 12a are each provided with attaching means 14 (Fig. 2) for attaching the respective unit to a surface 15 (Fig. 5A) along which the robot system is to move or to be transferred to or from in the course of perambulation and at or in the vicinity of which work of one kind or another is to be performed by the robot system. The attachment of the robot unit base 11a or 12a to the surface 15 is selectable, thus selectably securable to and releasable from the surface. This attach-and-release facility is exercisable in such a way that the two units 11 and 12 can both be attached at the same time or both unattached at the same time and that just a selectable one of the units can be attached while the other unit is unattached. The selectable attachment and release capability forms the basis of the ambulatory motion of which the system is capable.

The attaching means 14 can be provided in various forms, but in the illustrated embodiment comprises mechanical fixing means with electrical operation, in effect an electromechanical locking device. This can comprise, for example, one element 14a of a co-operating plug and socket - or other such mating components - provided in the base 11a or 12a, the other element 14b then being provided in the surface 15 or, more specifically, in a substrate furnished with the surface. Either the element 14a or the element 14b can be extensible for engagement in the respective other element so as to enable attaching to the surface 15 and also retractable for disengagement from the other element so as to enable release from the surface. When interengaged, the two elements 14a and 14b can be interlocked by a suitable locking arrangement, for example projections able to be driven out to locate in an undercut or in passages or other openings. The

projections can subsequently be withdrawn to cancel the interlocking and allow disengagement of the elements 14a and 14b. Drive of the projections or other such positive locking components can be provided by a solenoid or other suitable electrical actuator.

It is also possible for the attaching means 14 to comprise magnetic fixing means or suction fixing means. In the case of a ferromagnetic surface 15 to which the units 11 and 12 are to be attached, an electromagnetic fixing device can be provided in each of the bases 11a and 12a of the units so that adaptation of the surface 15 is not required. Similarly, a suction generating device provided in each base 11a and 12a may generate attachment by suction, again without any requirement to modify the surface. Mechanical fixing means may, in general, provide a stronger level of attaching force and consequently will be preferred in the case of robot systems required to perform more demanding tasks; however, magnetic attraction or adhesion by sub-atmospheric pressure may be more than sufficient in the case of lighter duties, such as inspection, which place lower demands on adhesion of the robot units 11 and 12 to the surface 15.

The coupling linkage 13 is formed by two elongate members or links, specifically limbs 16 and 17, articulated to one another and, at mutually remote ends, respectively to the head 11b of the robot unit 11 and head 12b of the robot unit 12. The points of articulation are formed by pivot axles or pins which conjunctively permit pivotation of the limbs relative to one another and to the units in a single plane. Each head 11b and 12b has a slot-like recess 18 which receives an end portion of the associated limb 16 or 17 and accommodates the respective pivot axle or pin, while allowing articulation to the units 11 and 12 close to the base 11a or 12a. The recesses 18 allow reception of a varying lengths of the limbs, depending on their orientation with respect to the units 11 and 12, to such an extent that the limbs are able to extend in coaxial alignment for maximum mutual spacing of the units. Although the form of articulation in the described embodiment limits pivotation to a single plane, thus in two dimensions, also possible is pivotation in multiple planes, thus in three dimensions, through use of universal joints or similar in place of simple axles. In that case, construction of each unit 11 and 12 from relatively rotatable parts (base and head) might be able to be dispensed with without loss of the scope of ambulation indicated further below, particularly in connection with Figs. 4A to 4D. However, control of the orientations of the limbs relative to one another and to the robot units would have to be provided so that the components could not freely pendulate in ways otherwise prevented

by the single-axis articulation points of the limbs and units in the described embodiment. It will be appreciated that with respect to the concept of ambulation represented by the robot system 10 with limbs 16 and 17 articulated to one another and to the robot units 11 and 12 the limbs correspond with legs and the units correspond with feet at the terminations of the legs, but unlike prior art systems there is no body from such legs depend. Ambulation is achieved, as explained below, by the selective attachment of the units to the surface or surfaces over which the robot system is to travel. Conversely, with respect to coupling of the units 11 and 12 of the system 10 so that the units are linked, the limbs correspond with arms. As will be evident from the further description, the limbs 16 and 17 have a dual character and function as both legs and arms in different circumstances.

The drive means for displacing the coupling linkage 13 to produce ambulation of the robot units 11 and 12 comprises an individual electric rotary drive motor 19 at each of the three points of articulation or pivot points of the limbs 16 and 17. The three drive motors 19 (two visible in Figs. 1 to 3) are individually operable to vary the orientations of the limbs with respect to one another and to the robot units by pivotation of the limb 16 relative to the unit 11, the limb 17 relative to the unit 12 and the limbs 16 and 17 relative to one another. The range of pivotation in each case can be up to 180 degrees in a single plane depending on the constraints of adjoining surfaces of the limbs and units. Operation of the motors 19 is controlled by appropriate on-board controllers on the basis of algorithms devised so that the motors can generate the degrees of pivotation of the limbs relative to one another and to the robot units to produce - in conjunction with controlled relative rotation of the base 11a, 12a and head 11b, 12b of either or each unit 11 and 12 about the respective axis A - walking motions of varying levels of complexity. One such motion is represented by the simple example illustrated in Figs. 5A to 5F (see below), which shows a step achieved by variably bending the limbs relative to one another in a vertical plane and swivelling in a horizontal plane to travel on a path about one of axes A in simulation of one form of human ambulation. The combination of variable bending of the limbs and relative rotation of the base and head of the or each robot unit results in three-dimensional movement of the robot system, subject to the requirement that during this movement one of the robots units, in particular that initially leading in a direction of progression, remains attached to the surface 15 while the other unit is detached from the surface. The three-dimensional movement of the system, in the form of ambulation, is realised by operation of the described drives in the system so that the limbs are reoriented to raise a detached one of the robot units from the surface 15, to rotate the head relative to the base of the still-

attached one of the units on a curved path about the axis A of the latter so as to reposition the detached unit relative to the attached unit through any desired angle, for example 180 degrees in the case of ambulation of the robot systems along a straight path, and finally to reverse the reorientation of the limbs so as to lower the detached one of the units back onto the surface 15. When the drives of, in particular, the limbs are not in operation the limbs are locked so that the instantaneous orientations of the limbs relative to one another and to the units are maintained. The result is that of a walking step of the detached unit relative to the attached unit. It is also conceivable, in the case of rectilinear travel, to simply swing the detached unit over the top of the attached unit; however, the combination of limb pivotation relative to one another and to the robot units and relative rotation of the base and head of the attached robot unit allows travel not only along a continuous, substantially planar horizontal surface, but also transfer between and movement along inclined and vertical surfaces. The surface attachment of the units, even when only one unit is attached, permits movement over non-horizontal surfaces without slipping or dislocation. Further, because pivotation of the limbs 16 and 17 relative to one another and to the robot units 11 and 12 is confined to one plane and limited to that plane by mutually adjacent surfaces forming abutments, the limbs cannot bend or deflect in undesired directions. If the limbs were to have a three-dimensional movement capability, such as by universal joints, this capability would have to be selectively controlled to limit the relative orientations of the limbs.

The operation of the various drives can also be subject to an additional superordinate remote control, such as via short-range radio transmission. Alternatively, drive operation could, if desired, be controlled entirely remotely.

A functionality of the robot system 10 can be realised by equipping either or each of the robot units 11 and 12, particularly their heads 11b and 12b, with suitable functional units. However, the utility of the system can be enhanced to a particular degree by a construction in which one of the limbs, such as the limb 16, is detachable from the associated robot unit, i.e. the unit 11 in the case of the limb 16. The other limb, thus the limb 17, can remain attached to - preferably permanently connected with - the associated unit, thus the unit 12, so that when the limb 16 is detached from the unit 11 the two limbs form a jib arm cantilevered from the unit 12. The detached or free end of the limb 16 is provided with a functional component 20, for example a tool holder to which a tool can be fitted. Fitting of a tool can be carried out automatically, such as by selection or acquisition

from a magazine on board either of the robot units. Fig. 3 shows the limb 16 detached from the robot unit 11 and equipped with a tool holder in the form of, by way of example, a chuck in which a drill bit is held. In this configuration, the limbs 16 and 17 transfer from a leg function for walking to an arm function for grasping and manipulating, thus transform from legs into arms. By virtue of the relative rotational capability present within each unit, the unit, in this case the unit 12, fitted with the component 20 can be operated to move the component 20 to anywhere within a range of 360 degrees around the unit.

The robot system 10 is provided with an on-board power source (not shown), such as a battery, to provide drive power for the rotary drive units between each unit base 11a or 12a and head 11b or 12b and for the motors 19 for pivoting the limbs 16 and 17 relative to one another and to the respective robot units 11 and 12. The power source is preferably housed in the robot units, especially an individual battery in each unit. Additionally or alternatively, the robot system 10 could be equipped with on-board power pick-up means (not shown) for picking up electrical current for the drives from a power source associated with the surface 15, in particular a substrate having the surface, or surfaces to which the robot units 11 and 12 are to be attached. In the case of, for example, mechanical fixing means, such as a plug and socket, for attachment of the units 11 and 12 to the surface 15 an electrical connection can be incorporated in the fixing means so that a dual purpose is provided by the attachment.

Finally, since it may be advantageous for the robot units 11 and 12 to be able to travel conjunctively, in effect as a team, intercoupled by way of the limbs 16 and 17 functioning purely as arms, or independently of one another, thus when the coupling linkage is uncoupled from one of the units, at a greater speed over the surface 15 to, for example, reach a particular destination from where ambulation may be commenced, each of the robot units comprises traction means for applying traction to the surface so as to be able to travel over the surface in a continuous rather than walking motion. Such traction means, which is intended to be effective only when the respective unit 11 or 12 is detached from the surface 15, can comprise, for example, protruding drivable tracks, wheels or - as in the case of the illustrated embodiment (cf. Fig. 2) - rollers 21, which are provided in diametrically opposite positions on the free circular face of the base 11a or 12a of the respective robot unit 11 or 12. More than two, for example three or four, such rollers can be provided, but in a simple embodiment with minimised drive complexity only two such rollers are present at each robot unit and stability of the unit is achieved by spaced-apart

and freely rollable surface-engaging balls 22 captively retained at and protruding from the circular face of the respective base 11a or 12a. The rollers 21 can be driven conjunctively, for example by a switchable take-off from a drive in the unit base, or independently if a turning capability of the respective robot unit is desired.

Figs. 4A to 4C show, merely by way of example, some of the ambulation capabilities of the robot system 10. Fig. 4A depicts travel of the robot units 11 and 12 of the system along a planar horizontal surface 15a and Fig. 4B transfer of the unit 11 in detached state to an adjoining vertical surface 15b while the unit 12 remains attached to the surface 15a, the two surfaces 15a and 15b representing mutually perpendicular faces of a single beam or strut. Fig. 4C shows attachment of both units 11 and 12 to the vertical surface 15b, along which the units can walk provided one of the units always remains attached to the surface 15b. As is apparent, since the articulation of the limbs 16 and 17 to one another and to the units 11 and 12 is confined to a single plane, thus to two dimensions, even when only one of the units is attached to the surface 15a the unattached unit and the limbs are incapable of unintentional deflection from that plane; deflection from the plane is possible only when the drives of the limbs or of the base and head parts of the units are operated.

Figs. 5A to 5F are schematic diagrams showing principal components of the robot system 10, in particular the two robot units 11 and 12 and articulated limbs 16 and 17, in sequential phases of execution of one step in walking movement along a simple rectilinear path to the right in the figures, the system components being shown in elevation in an upper row and in corresponding phase in plan in a lower row. The path is along the surface 15, in particular horizontal surface 15a, which is indicated in the upper row by an interrupted horizontal line with associated hatching denoting a substrate provided with the surface. In Fig. 5A both robot units 11 and 12 are attached by the respective attaching means to the surface. In Fig. 5B the lefthand unit 11 is released from the surface, while the righthand unit 12 remains attached, and the drive motors are operated to not only lift the unit 11 by appropriate pivotation of the limbs 16 and 17 relative to one another and to the units 11 and 12, but also to rotate the head 12b relative to the attached base 12a of the unit 12 (in clockwise direction of the unit as seen in plan view) about the axis A of the unit 12 so as to swing the unattached unit 11 around the still attached unit 12, thus cause it to travel on a path around that axis A. Progression of the swinging motion is shown in Figs. 5C and 5D, after which the unit 11 is aligned with a desired or predetermined new location and lowered back onto the surface 15a as shown in Fig. 5E. The ambulatory

robot system 10 has thus executed a single step. A further step in the same direction by a corresponding procedure or a step to another, possibly relatively angled, surface (such as surface 15b) can then follow depending on the task assigned to the system. Alternatively, after execution of the step the limb 16 can be detached from the unit 11 and the thus-freed end, which can have the functional component 20 such as a tool holder as previously mentioned, of the limb 16 can acquire a tool as shown in Fig. 5F in order to perform a desired operation, for which purpose the unit 12 is now also be attached to the surface. The diagrams of Figs. 5A to 5F illustrate merely a basic step of the walking regime within the capabilities of the robot system 10; the above-described Figs. 4A to 4C evidence further available steps in this regime.

An ambulatory robot system 10 embodying the present invention provides a different approach to robot ambulation by utilisation of surface attachment and consequently exhibits a capability of a traversing not only horizontal surfaces, but also inclined and vertical surface, where selected tasks can be performed depending on the functionality or functionalities incorporated in the system.

CLAIMS

1. An ambulatory robot system comprising

two robot units each provided with attaching means for use in selectably attaching the respective unit to and detaching that unit from a surface,

coupling means coupling the units together to be relatively movable for varying their positional relationship

and drive means for displacing the coupling means to produce the relative movement when either one of the units is detached from a surface while the respective other unit remains attached to a surface,

the detached robot unit being rotatable relative to the attached unit to allow the detached unit to travel on a path around an axis of the attached unit.

2. A system according to claim 1, wherein at least one of the robot units comprises two relatively rotatable parts, the attaching means of each robot unit being provided on one of those parts and the coupling means being connected with the other part of the respective unit.

3. A system according to claim 1 or claim 2, wherein the path is a curved path in two or three dimensions.

4. A system according to claim 3, wherein the curved path is at least part of a circle or an ellipse or is a parabola.

5. A system according to any one of the preceding claims, wherein the coupling means is displaceable by the drive means to allow the robot units to move along a substantially planar surface or between and along two relatively angled surfaces.

6. A system according to any one of the preceding claims, wherein the coupling means is displaceable by the drive means to raise, lower and tilt the detached robot unit relative to the attached unit and to move the detached unit towards and away from the

attached unit.

7. A system according to any one of the preceding claims, wherein the coupling means comprises a plurality of limbs articulated to each other and to the robot units and the drive means is operable to vary orientations of the limbs relative to one another and the robot units.

8. A system according to claim 7, wherein the limbs are articulated to be movable relative to one another and to the robot units in a single plane.

9. A system according to claim 7, wherein the limbs are articulated to be movable relative to one another and to the robot units in multiple planes.

10. A system according to any one of claims 7 to 9, wherein the limbs are engaged in recesses in the robot units and articulated to the robot units within the recesses.

11. A system according to any one of the preceding claims, wherein the coupling means is uncouplable from and recouplable to at least one of the robot units.

12. A system according to claim 11, wherein the coupling means is provided with a functional component at an end thereof uncouplable from and recouplable to the at least one of the robot units.

13. A system according to claim 12, wherein the functional component is a tool holder.

14. A system according to any one of the preceding claims, wherein the attaching means of each robot unit comprises mechanical fixing means.

15. A system according to claim 14, wherein the mechanical fixing means is constructed for interlocking with co-operating fixing means at a surface to which the respective robot unit is to be attached.

16. System according to claim 15, wherein the mechanical fixing means is a plug or socket.

17. A system according to any one of the preceding claims, wherein the attaching means of each robot unit comprises magnetic fixing means.
18. A system according to claim 17, wherein the magnetic fixing means comprises an electromagnetic fixing device for generating a magnetic field for attraction to a ferromagnetic surface.
19. A system according to any one of the preceding claims, wherein the attaching means of each robot unit comprises suction fixing means.
20. A system according to any one of the preceding claims, comprising an on-board power source for supplying the drive means with operating power.
21. A system according to any one of the preceding claims, comprising power pick-up means for picking up operating power for the drive means from a power source associated with the surface or surfaces to which the robot units are to be attached.
22. A system according to any one of the preceding claims, wherein each of the robot units comprises traction means for applying traction to a surface, when the respective robot unit is detached therefrom, to move the detached robot unit over the surface.
23. A system according to claim 23, wherein the coupling means is uncouplable from one of the robot units to allow either or each of the robot units, when detached from a surface, to move over the surface independently of the respective other robot unit.



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Claims searched: 1 to 23

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Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1 to 8 and 11 to 20	US 2018/099710 A1 (HAFENRICHTER et al.) figures 3 to 10 and 15

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

B25J; B62D

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
B25J	0009/16	01/01/2006
B25J	0005/00	01/01/2006
B25J	0009/08	01/01/2006
B25J	0011/00	01/01/2006
B62D	0057/032	01/01/2006