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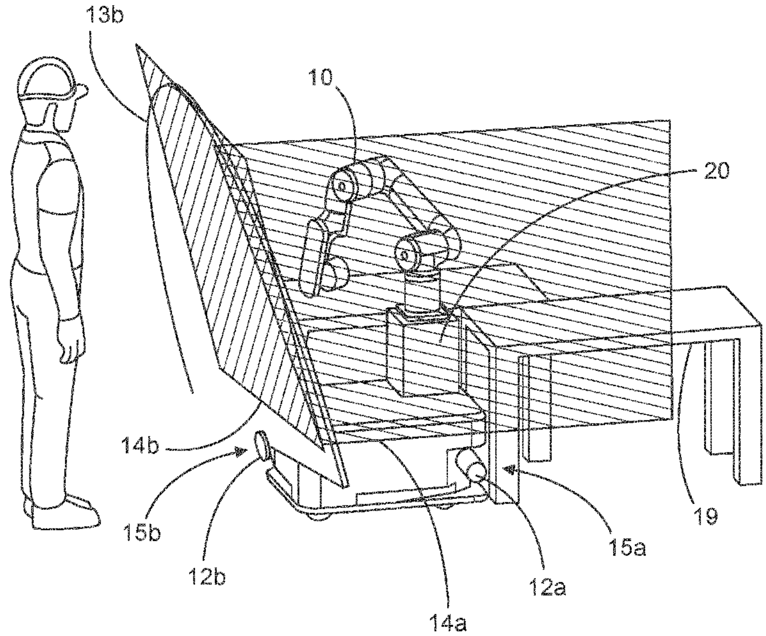


Fig. 3

(57) **Abstract:** The present invention relates to a robot system, comprising: - a robot body (11); - a manipulator (10); - a control unit (20); and - at least one laser scanner (12); wherein the manipulator is mounted to the robot body; wherein the at least one laser scanner is mounted to the robot body; wherein the control unit is configured to move the manipulator relative to the robot body and/or control activation of the manipulator; wherein the control unit is configured to define at least one areal protective zone (14) at a periphery of the robot body, and wherein each areal protective zone of the at least one areal protective zone is defined at an angle between 45-90 degrees to the horizontal; wherein the control unit is configured to control the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one areal protective zone and acquire at least one sensor data for reflected laser radiation within at least one coverage range or scan plane (13) within the at least one 2D plane, wherein each 2D plane is coplanar with an areal protective

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zone, and wherein each laser scanner is configured to project laser radiation in a 2D plane coplanar with an areal protective zone and acquire sensor data for reflected laser radiation within a coverage range or scan plane within the 2D plane that is at least a significant proportion of the areal protective zone; and wherein the control unit is configured to trigger a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane.

# ROBOT SYSTEM

## FIELD OF THE INVENTION

The present invention relates to a robot system and method of controlling a robot.

## BACKGROUND OF THE INVENTION

Robot manipulators on automatically guided vehicles (AGVs) or autonomous mobile robots (AMRs) need to sense their immediate surroundings to avoid collision of the vehicle or the manipulator with objects or persons. It is a challenge to select the right sensor technologies and sensor components. The positioning and arrangement of sensors is part of this challenge.

Safety laser scanners are installed on an AGV, which scan a plane that is parallel to the floor at a height of about 5-15 cm. Since usually there are multiple AGVs it is common practice to mount a laser scanner slightly tilted by +/- ~1° to minimize interference between laser scanners on different AGVs. Such a laser scanner can safeguard the vehicle by enabling the vehicle to slow down or stop motion if an object or person is detected in a pre-defined protective zone.

In order to use the same laser scanners for safeguarding of manipulator motion during vehicle standstill, large safety distances are required (cf. ISO 13855, ISO/TS15066): Since the scanners can only detect intrusion of the legs of an approaching person, the worst-case assumption of the person leaning and reaching out towards the manipulator workspace must be considered. Taking into account also sensor and machine reaction and stopping times, this will easily yield safety distances in the range of 1.5 to 2 m and above, which are not feasible in many applications (see Fig. 1, which shows a known robot system with 2D safety laser scanners that monitor the safety distance and that triggers a safe stop, that must be set with a considerable safety margin because it must be assumed that undetected upper body parts reach out, and that person and robot move towards each other). Adding separate additional safety sensors for the manipulator is typically not accepted for cost reasons.

Thus, AGVs and mobile robots are safeguarded by 1-2 2D laser scanners that are usually mounted on opposite corners with their scan fields aligned horizontally at low height above the floor. A moving machine or robot mounted on the vehicle are then safeguarded by the same scanners during vehicle movement and standstill. However, large safety distances around the vehicle are necessary since the scanners can only detect the legs of an approaching person. These considerable safety margins are required because a person can reach out toward the robot and thus be much closer than their detected feet or even be carrying something that can be much closer the robot that the persons outstretched arm. This, however, prevents many practical applications due to uneconomical floor space requirements – in practice, there is rarely enough clearance around the vehicle and neighboring structures would occlude the sensor view.

There is a need to address these issues.

## SUMMARY OF THE INVENTION

Therefore, it would be advantageous to have an improved robot safety system.

The object of the present invention is solved with the subject matter of the independent claim, wherein further embodiments are incorporated in the dependent claims.

In a first aspect, there is provided a robot system, comprising:

- a robot body;
- a manipulator;
- a control unit; and

- at least one laser scanner.

The manipulator is mounted to the robot body. The at least one laser scanner is mounted to the robot body. The control unit is configured to move the manipulator relative to the robot body and/or control activation of the manipulator. The control unit is configured to define at least one areal protective zone at a periphery of the robot body, and each areal protective zone of the at least one areal protective zone is defined at an angle between 45-90 degrees to the horizontal. The control unit is configured to control the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one areal protective zone and acquire at least one sensor data for reflected laser radiation within at least one coverage range or scan plane within the at least one 2D plane. Each 2D plane is coplanar with an areal protective zone. Each laser scanner is configured to project laser radiation in a 2D plane coplanar with an areal protective zone and acquire sensor data for reflected laser radiation within a coverage range or scan plane within the 2D plane that is at least a significant proportion of the areal protective zone. The control unit is configured to trigger a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane.

An areal protective zone is a 2D area that can be in effect a 2D plane with zero thickness, or can be a volume, where the volume has a small thickness perpendicular to the 2D plane, where the thickness is small in comparison to dimensions in the 2D plane.

In an example, each laser scanner of the at least one laser scanner is mounted on a swivel mechanism. The control unit is configured to control the swivel mechanism for each laser scanner to vary an angle of the projected laser radiation in the 2D plane at an angle between 45-90 degrees to the horizontal.

In an example, the control unit is configured to define a workspace around the manipulator based on a work schedule of the manipulator. The control unit is configured to define each protective zone of the at least one areal protective zone at an angle between 45-90 degrees to the horizontal to maintain at least a clearance distance between the at least one areal protective zone and the workspace.

In an example, the control unit is configured to define a size of the workspace dependent upon specific tasks within the work schedule.

In an example, the robot system comprises at least one visual indicator, and each visual indicator is configured to project visible light in a 2D plane. The control unit is configured to control one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes aligned with and adjacent to the at least one coverage range or scan plane.

In an example, the robot system comprises at least one visual indicator, and each visual indicator is configured to project visible light in a 2D plane. The control unit is configured to control one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes directed at the floor to indicate one or more locations of one or more outer extents of the at least one coverage range or scan plane.

In an example, the robot body is a vehicular robot, and the control system is configured to control the robot body to move. When the robot body is moving the control unit is configured to:

- define at least one horizontal areal protective zone at a periphery of the robot body, and wherein each horizonal areal protective zone of the at least one horizontal areal protective zone is defined at an angle between -5-5 degrees to the horizontal;
- control the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one horizontal areal protective zone and acquire at least one sensor data for reflected laser radiation within at least one coverage range or scan plane within the at least one 2D plane, wherein each 2D plane is coplanar with a horizontal areal protective zone, and wherein each laser scanner is configured to project laser radiation in a 2D plane coplanar with a horizontal areal protective zone and acquire sensor data for reflected laser radiation within a coverage range or scan plane within the 2D plane that is at least a significant proportion of the horizontal areal protective zone; and
- trigger a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane

within the at least one 2D plane coplanar with the at least one horizontal areal protective zone.

In a second aspect, there is provided a method of controlling a robot. A manipulator is mounted to a robot body of the robot and a control unit is configured to move the manipulator relative to the robot body and/or control activation of the manipulator, and at least one laser scanner is mounted to the robot body. The method comprises:

- defining, by the control unit, at least one areal protective zone at a periphery of the robot body, and wherein each areal protective zone of the at least one areal protective zone is defined at an angle between 45-90 degrees to the horizontal;
- controlling, by the control unit, the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one areal protective zone, wherein each 2D plane is coplanar with an areal protective zone, and wherein each laser scanner is configured to project laser radiation in a 2D plane coplanar with an areal protective zone;
- acquiring, by the at least one laser scanner, at least one sensor data for reflected laser radiation within at least one coverage range or scan plane within the at least one 2D plane if an object is present within a coverage range or scan plane of the at least one coverage range or scan plane, and wherein each coverage range or scan plane within a 2D plane is at least a significant proportion of the associated areal protective zone; and
- triggering, by the control unit, a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane.

According to an example, each laser scanner of the at least one laser scanner is mounted on a swivel mechanism, and the method comprises:

- controlling, by the control unit, the swivel mechanism for each laser scanner to vary an angle of the projected laser radiation in the 2D plane at an angle between 45-90 degrees to the horizontal.

According to an example, the method comprises:

- defining, by the control unit, a workspace around the manipulator based on a work schedule of the manipulator; and

- defining, by the control unit, each protective zone of the at least one areal protective zone at an angle between 45-90 degrees to the horizontal to maintain at least a clearance distance between the at least one areal protective zone and the workspace.

According to an example, the method comprises:

- defining, by the control unit, a size of the workspace dependent upon specific tasks within the work schedule.

According to an example, at least one visual indicator is mounted to the robot, and each visual indicator is configured to project visible light in a 2D plane, and the method comprises:

- controlling, by the control unit, one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes aligned with and adjacent to the at least one coverage range or scan plane.

Method according any of claims 8-12, wherein at least one visual indicator is mounted to the robot, wherein each visual indicator is configured to project visible light in a 2D plane, and wherein the method comprises:

- controlling, by the control unit, one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes directed at the floor to indicate at one or more locations of one or more outer extents of the at least one coverage range or scan plane.

According to an example, the robot is a vehicular robot, and wherein the robot is moving the method comprises:

- defining, by the control unit, at least one horizontal areal protective zone at a periphery of the robot body, and wherein each horizonal areal protective zone of the at least one horizontal areal protective zone is defined at an angle between -5-5 degrees to the horizontal;
- controlling, by the control unit, the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one horizontal areal protective zone, wherein each 2D plane is coplanar with a

horizontal areal protective zone, and wherein each laser scanner is configured to project laser radiation in a 2D plane coplanar with a horizontal areal protective zone;

- acquiring, by the at least one laser scanner, at least one sensor data for reflected laser radiation within at least one coverage range or scan plane within the at least one 2D plane if an object is present within a coverage range or scan plane of the at least one coverage range or scan plane, and wherein each coverage range or scan plane within a 2D plane is at least a significant proportion of the associated horizontal areal protective zone; and
- triggering, by the control unit, a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane coplanar with the at least one horizontal areal protective zone.

According to another aspect, there is provided a computer program element controlling one or more of the systems as previously described which, if the computer program element is executed by a processor, is adapted to perform one or more of the methods as previously described.

According to another aspect, there is provided a computer readable medium having stored a computer element as previously described.

The computer program element can for example be a software program but can also be a FPGA, a PLD or any other appropriate digital means.

The above aspects and examples will become apparent from and be elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

Exemplary embodiments will be described in the following with reference to the following drawing:

Fig. 1 shows an example of a known robot system;

Fig. 2 shows an example of the new robot system;

Fig. 3 shows an example of the new robot system; and

Fig. 4 shows an example of the new robot system.

## DETAILED DESCRIPTION OF EMBODIMENTS

Figs. 2-4 relate to a new robot system and method of controlling a robot.

In an example, a robot system comprises:

- a robot body 11;
- a manipulator 10;
- a control unit 20; and
- at least one laser scanner 12.

The manipulator is mounted to the robot body. The at least one laser scanner is mounted to the robot body. The control unit is configured to move the manipulator relative to the robot body and/or control activation of the manipulator. The control unit is configured to define at least one areal protective zone 14 at a periphery of the robot body, and each areal protective zone of the at least one areal protective zone is defined at an angle between 45-90 degrees to the horizontal. When there are more than one areal protective zone, the areal protective zones can be all at the same angle to the horizontal to each other or all be at different angles to the horizontal to each other. The control unit is configured to control the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one areal protective zone and acquire at least one sensor data for reflected laser radiation within at least one coverage range or scan plane 13 within the at least one 2D plane. When there are more than one laser scanner, each 2D plane is coplanar with an areal protective zone, and each laser scanner is configured to project laser radiation in a 2D plane coplanar with an areal protective zone and acquire sensor data for reflected laser radiation within a coverage range or scan plane within the 2D plane that is at least a significant proportion of the areal protective zone. The control unit is configured to trigger a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane.

An areal protective zone is a 2D area that can be in effect a 2D plane with zero thickness, or can be a volume, where the volume has a small thickness perpendicular to the 2D plane, where the thickness is small in comparison to dimensions in the 2D plane.

It is also to be noted that control unit 20 can be a part of a laser scanner 12, and indeed “a control unit” is used in a broad sense and can mean a plurality of control units, and again if there are a plurality of laser scanners 12 then each can have a control unit 20. However, the control unit 20 or control units 20 can be separate to the laser scanners.

Thus a single control unit 20 can define an areal protective zone 14 or a plurality of areal protective zones 14 and indeed if there are a plurality of control units 20, whether part of or associated with a plurality of laser scanners 12 then each control unit 20 can define a protective zone with respect to a laser scanner 12 with which it is a part or associated, and each laser scanner 12 projects laser radiation appropriately.

The control unit 20 or plurality of control units can be programmed with a list of different safety zones 14 and only one or a few can be active at one time dependent upon what the manipulator 10 of the robot system is doing. Thus, the control unit 20 can select the proper zones 14 which must be activated – depending on the status of the robot system.

Also, reference to a control unit 20 that controls the manipulator 10 in some way and that controls the laser scanner 12 or laser scanners 12 is again refers to a control unit in a general sense and the manipulator 10 and laser scanner(s) 12 can be controlled by different control units 20.

It is also to be noted that a manipulator 10 is used as a general term, that covers for example a robotic arm, a powered attachment, a tool etc. Thus, the manipulator can move like an arm or could be a stationary power tool or attachment that is activated or be a movable power tool or attachment.

With respect to triggering of the safety response, this can be considered to occur that if the laser scanner 12 detects something within the safety zone 14 it sends a signal to the control unit 20 which in turn triggers a safety response.

In an example, the control unit is mounted on the robot body.

In an example, the control unit is external to the robot body and sensor data is transmitted to the control unit and commands are transmitted from the control unit to the robot.

In an example, the safety response comprises instructions to stop motion of the manipulator.

In an example, the safety response comprises instructions to change motion of the manipulator.

In an example, the at least one laser scanner is at least one Infrared (IR) laser scanner.

In an example, the at least one laser scanner is at least one visible laser scanner.

In an example, each laser scanner has a laser emitter source and a laser radiation detector.

In an example, each laser scanner has a timing circuit that only detects or selects radiation incident on the laser radiation detector within a time limit of emission. Thus, a pulse of radiation can be emitted, when the radiation travels approximately 30cm per nanosecond. The laser scanner can be set to only detector or select radiation within a time window of 20 nanoseconds. Thus laser radiation emitted from the laser of the laser scanner that interacts with an object and scatters back to the detector of the laser scanner must be within 3m of the laser scanner. This means that the laser scanner can emit radiation in a 2D plane that continues and hits for examples walls of a building within which the robot system is located and some of this radiation will scatter back to the detector of  the laser scanner. But the laser scanner is only actually detecting objects in the first 3m of the 2D plane from the laser scanner. This is how a coverage range or scan plane within the 2D plane or emitted laser radiation is defined, within which objects can be detected.

According to an example, each laser scanner of the at least one laser scanner is mounted on a swivel mechanism 15. The control unit is configured to control the swivel mechanism for each laser scanner to vary an angle of the projected laser radiation in the 2D plane at an angle between 45-90 degrees to the horizontal.

According to an example, the control unit is configured to define a workspace 21 around the manipulator based on a work schedule of the manipulator. The control unit is configured to define each protective zone of the at least one areal protective zone at an angle between 45-90 degrees to the horizontal to maintain at least a clearance distance 23 between the at least one areal protective zone and the workspace.

According to an example, the control unit is configured to define a size of the workspace dependent upon specific tasks within the work schedule.

Thus, as the manipulator moves faster and/or makes larger movements, the workspace can be increased in size appropriately and the protective zones, and the associated 2D projected laser planes, become more angled away from the robot – they become less vertical. This ensure that a person will trigger a safety response at a greater distance from the manipulator as the manipulator become potentially more dangerous.

According to an example, the robot system comprises at least one visual indicator 26, and each visual indicator is configured to project visible light in a 2D plane. The control unit is configured to control one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes 27 aligned with and adjacent to the at least one coverage range or scan plane.

Thus, a person can in effect see the protective zones around the robot, because there are sheets of visible light aligned with the protective zones, for example slightly outside of the protective zones with respect to the robot, and act accordingly.

In an example the at least one visual indicator comprises a visible laser scanner.

In an example the at least one visual indicator comprises a visible LED scanner.

It is to be noted that when the at least one laser scanner that is used to project laser radiation in at least one 2D plane that is coplanar with the at least one areal protective zone is at least one visible laser scanner, then the at least one visual indicator is in effect the at least one laser scanner.

According to an example, the robot system comprises at least one visual indicator 26, and each visual indicator is configured to project visible light in a 2D plane. The control unit is configured to control one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes 28 directed at the floor to indicate one or more locations of one or more outer extents of the at least one coverage range or scan plane.

Thus, can in effect see the protective zones around the robot, because there are sheets of visible light aligned with the protective zones that form a line on the ground, for example aligned with a centre or top of the protective zones, and act accordingly.

In an example the at least one visual indicator comprises a visible laser scanner.

In an example the at least one visual indicator comprises a visible LED scanner.

According to an example, the robot body is a vehicular robot, and the control system is configured to control the robot body to move. When the robot body is moving the control unit is configured to:

- define at least one horizontal areal protective zone 14 at a periphery of the robot body, and wherein each horizonal areal protective zone of the at least one horizontal areal protective zone is defined at an angle between -5 to 5 degrees to the horizontal;
- control the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one horizontal areal protective zone and acquire at least one sensor data for reflected laser radiation within at least one coverage range or scan plane 13 within the at least one 2D plane, wherein each 2D plane is coplanar with a horizontal areal protective zone, and wherein each laser scanner is configured to project laser radiation in a 2D plane coplanar with a

horizontal areal protective zone and acquire sensor data for reflected laser radiation within a coverage range or scan plane within the 2D plane that is at least a significant proportion of the horizontal areal protective zone; and

- trigger a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane coplanar with the at least one horizontal areal protective zone.

Thus, the robot system can relate to a robot body 11 that is stationary or relate to a robot body 11 that is a vehicle, with a powered attachment such as a manipulator, and one or more laser scanners 12 that are mounted on swivel mechanisms. When the robot body is moving, the laser scanner(s) are tilted into horizontal orientations (+/- a few deg, and they safeguard the robot body as it is moving as a vehicle. When the robot body 11 is parked or docked the laser scanner(s) are tilted up to approximately 45 to 90 degrees to safeguard the manipulator such as a robot arm or powered attachment. Here, “safeguard” means that if the laser scanner or scanners 12 detect something in one or more safety zones 14, then the laser scanner or scanners send(s) a signal to the control unit 20, and the control unit 20 triggers a safety response.

In an example, the safety response comprises instructions to stop motion of the robot body.

In an example, the safety response comprises instructions to change motion of the robot body.

An exemplar method of controlling a robot is now described. A manipulator is mounted to a robot body of the robot and a control unit is configured to move the manipulator relative to the robot body and/or control activation of the manipulator, and at least one laser scanner is mounted to the robot body. The method comprises:

- defining, by the control unit, at least one areal protective zone at a periphery of the robot body, and wherein each areal protective zone of the at least one areal protective zone is defined at an angle between 45-90 degrees to the horizontal;

- controlling, by the control unit, the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one areal protective zone, wherein each 2D plane is coplanar with an areal protective zone, and wherein each laser scanner is configured to project laser radiation in a 2D plane coplanar with an areal protective zone;
- acquiring, by the at least one laser scanner, at least one sensor data for reflected laser radiation within at least one coverage range or scan plane within the at least one 2D plane if an object is present within a coverage range or scan plane of the at least one coverage range or scan plane, and wherein each coverage range or scan plane within a 2D plane is at least a significant proportion of the associated areal protective zone; and
- triggering, by the control unit, a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane.

In an example, the control unit is mounted to the robot body.

In an example, the control unit is external to the robot and sensor data is transmitted to the control unit and commands are transmitted from the control unit to the robot.

In an example, the safety response comprises instructions to stop motion of the manipulator.

In an example, the safety response comprises instructions to change motion of the manipulator.

According to an example, each laser scanner of the at least one laser scanner is mounted on a swivel mechanism, and the method comprises:
- controlling, by the control unit, the swivel mechanism for each laser scanner to vary an angle of the projected laser radiation in the 2D plane at an angle between 45-90 degrees to the horizontal.

According to an example, the method comprises:
- defining, by the control unit, a workspace around the manipulator based on a work schedule of the manipulator; and

- defining, by the control unit, each protective zone of the at least one areal protective zone at an angle between 45-90 degrees to the horizontal to maintain at least a clearance distance between the at least one areal protective zone and the workspace.

According to an example, the method comprises:

- defining, by the control unit, a size of the workspace dependent upon specific tasks within the work schedule.

According to an example, at least one visual indicator is mounted to the robot, and each visual indicator is configured to project visible light in a 2D plane, and the method comprises:

- controlling, by the control unit, one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes aligned with and adjacent to the at least one coverage range or scan plane.

According to an example, at least one visual indicator is mounted to the robot, and each visual indicator is configured to project visible light in a 2D plane, and the method comprises:

- controlling, by the control unit, one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes directed at the floor to indicate at one or more locations of one or more outer extents of the at least one coverage range or scan plane.

According to an example, the robot is a vehicular robot, and when the robot is moving the method comprises:

- defining, by the control unit, at least one horizontal areal protective zone at a periphery of the robot body, and wherein each horizonal areal protective zone of the at least one horizontal areal protective zone is defined at an angle between -5 to 5 degrees to the horizontal;
- controlling, by the control unit, the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one horizontal areal protective zone, wherein each 2D plane is coplanar with a

horizontal areal protective zone, and wherein each laser scanner is configured to project laser radiation in a 2D plane coplanar with a horizontal areal protective zone;

- acquiring, by the at least one laser scanner, at least one sensor data for reflected laser radiation within at least one coverage range or scan plane within the at least one 2D plane if an object is present within a coverage range or scan plane of the at least one coverage range or scan plane, and wherein each coverage range or scan plane within a 2D plane is at least a significant proportion of the associated horizontal areal protective zone; and
- triggering, by the control unit, a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane coplanar with the at least one horizontal areal protective zone.

In an example, the safety response comprises instructions to stop motion of the vehicular robot.

In an example, the safety response comprises instructions to change motion of the vehicular robot.

The robot system and method of controlling a robot are now described in further specific detail, where reference is again made to Figs. 2-4.

Fig. 2 shows an example of a robot system, where the robot body 11 is a vehicular robot, and is moving.  A powered attachment or a manipulator 10, is mounted to the robot body and 2D laser scanners 12a and 12b are placed at opposite corners of the robot body, which cover about 270 deg each. A control unit 20 is also located within the robot body. A protective zone 14 is defined by the control unit that takes into account how fast the robot is moving forward, where it will move next and its braking capability. The control unit has controlled the two laser scanners to swivel to project laser radiation in horizontal planes, and reflected radiation is detected within a coverage range or scan plane 13a associated with laser scanner 12a and within a coverage range or scan plane 13b associated with laser scanner 12b. Thus, as the robot vehicle drives automatically then the protective zone 14 is supervised by the laser scanners that detect objects within coverage range or scan plane 13a and coverage range or scan plane 13b that extend over the protective zone 14. If an object is detected in the protective zone then the vehicle slows down and stops. It is to be noted that the coverage range or scan plane 13a and coverage range or scan plane 13b can be as shown, where in effect detection timing for each laser scanner is the same at all angles, or the detection timing can vary with angle such that the coverage range or scan plane 13a and coverage range or scan plane 13b exactly match the protective zone 14.

As shown in Fig. 3, the robot body of Fig. 2 has arrived at its destination, which in this example is a dedicated work station formed by tables 19, forming an L shape, which restricts people from approaching the robot from two sides (the back and right hand side). The controller 20 then defines a protective zone 14a at the left side of the robot body and defines a protective zone 14b at the front side of the robot body that are slightly inclined outwards from the vertical, and these define safety planes that take into account operation of the manipulator 10, such that if an object for example a part of a person were to enter a protective zone, the controller would initiate a safety response such as stopping movement of the manipulator and/or inhibit it from moving. The controller 20 then controls a swivel mechanism 15a for laser scanner 12a that swings the laser scanner upwards to project a 2D plane of radiation coplanar with the protective zone 14a such that the coverage range or scan plane 13a covers protective zone 14a and could match it exactly. Similarly the controller 20 then controls a swivel mechanism 15b for laser scanner 12b that swings the laser scanner upwards to project a 2D plane of radiation coplanar with the protective zone 14b such that the coverage range or scan plane 13b covers protective zone 14b and could match it exactly. Thus, in effect different protective zones 14a, 14b are defined and actively scanned to form a “laser curtain” on two sides of the robot vehicle and work station such that the manipulator 10 and its workspace cannot be reached by a person without penetrating a protective zone, that if that were to occur renders the manipulator and workspace safe.

Fig. 4 shows further details of the robot system. The constrained workspace 21 of the manipulator and the angles 22a, 22b of the scanner fields 14 are defined such that there is a clearance 23 between this workspace 21 and the protective zone (scanner field) 14. Preferably this clearance 23 complies with the minimum distance S as defined in standards for machine safety such as ISO 13855.

In the “manipulator safeguarding” configuration as illustrated in Fig. 3 and Fig. 4, the protective zones (scanner fields) 14 can be vertical, with a tilt angle 22 at 90 deg. Alternatively the tilt angle can be less than 90 deg, which allows to adjust the distance 23 between the protective zone (scanner field) 14 and the manipulator workspace 21 or current manipulator position. This can be utilized to adjust for sensor and manipulator reaction and stopping times and/or to increase the allowable space for manipulator motion. If the tilt angle 22 is less than 90 deg then the geometry of the protective safety zones 14a, 14b are adjusted such that there is a small overlap at the intersection of 14a and 14b, and that the field reaches a desired height above ground.

The tilt angle 22 can be changed continuously in discrete pre-set steps or to pre-defined values in order to increase the effective safety distance between the robot and an approaching person.

The change of tilt angle can be made depending on the planned TCP speed of the manipulator: the faster it runs the more the field is tilted out of the vertical plane.

The change of tilt angle can be made depending on the planned zones in which the manipulator will move: if it only moves within the exposed 2 sides of the contour of the vehicle then the tilt angle can be ~90 deg; otherwise it would be tilted out of the vertical.

Additional visual indicators 26 can be mounted on the swivel, which visualize the actual scan planes 13, e.g. with shaped and directed light beams 27 outside and in parallel to the scan planes; this would visibly illuminate a body part before it would penetrate the protective zone (scanner field) 14. Another example is to direct the light to the floor 28, which marks the location of the scan field above. Optionally the light can be modulated or strobed for better visibility.

It is to be noted that rather than just two laser scanners, 12a and 12b, there can be three at three corners of the robot body, or indeed even four at four corners of the robot body, that can then provide protective zones 14 that completely encircle the robot when it utilizes its manipulator.

In another exemplary embodiment, a computer program or computer program element is provided that is characterized by being configured to execute the method steps of the method according to one of the preceding embodiments, on an appropriate processor or system.

The computer program element might therefore be stored on a computer unit, which might also be part of an embodiment. This computing unit may be configured to perform or induce performing of the steps of the method described above. Moreover, it may be configured to operate the components of the above described system. The computing unit can be configured to operate automatically and/or to execute the orders of a user. A computer program may be loaded into a working memory of a data processor. The data processor may thus be equipped to carry out the method according to one of the preceding embodiments.

This exemplary embodiment of the invention covers both, a computer program that right from the beginning uses the invention and computer program that by means of an update turns an existing program into a program that uses the invention.

Further on, the computer program element might be able to provide all necessary steps to fulfill the procedure of an exemplary embodiment of the method as described above.

According to a further exemplary embodiment of the present invention, a computer readable medium, such as a CD-ROM, USB stick or the like, is presented wherein the computer readable medium has a computer program element stored on it which computer program element is described by the preceding section.

A computer program may be stored and/or distributed on a suitable medium, such as an optical storage medium or a solid state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the internet or other wired or wireless telecommunication systems.

However, the computer program may also be presented over a network like the World Wide Web and can be downloaded into the working memory of a data processor from such a network. According to a further exemplary embodiment of the present invention, a medium for making a computer program element available for downloading is provided, which computer program element is arranged to perform a method according to one of the previously described embodiments of the invention.

Reference numerals

| | |
|---|---|
| 10 | manipulator (such as robot arm, attachment, powered |
| t | ool etc) |
| 11 | robot body (that can be a vehicle) |
| 12 | 2D laser scanner |
| 12a | 2D laser scanner |
| 12b | 2D laser scanner |
| 13 | coverage range or scan plane of laser scanner 12 |
| 13a | coverage range or scan plane of laser scanner 12a |
| 13b | coverage range or scan plane of laser scanner 12b |
| 14 | protective zone comprised within coverage range or scan plane 13 of scanner 12 |
| 14a | protective zone comprised within coverage range or scan plane 13a of scanner 12a |
| 14b | protective zone comprised within coverage range or scan plane 13b of scanner 12b |
| 15a | swivel mechanism for laser scanner 12a |
| 15b | swivel mechanism for laser scanner 12b |
| 19 | table |
| 20 | control unit |
| 21 | workspace of the manipulator 10 |
| 22 | tilt angle of coverage range or scan plane 13 of laser scanner 12 w.r.t horizontal |
| 22b | tilt angle of coverage range or scan plane 13b of laser scanner 12b w.r.t horizontal |
| 23 | clearance between protective zone 14 and workspace 23 of the manipulator 10 |
| 26 | visual light indicator |
| 27 | light beam generated by visual light indicator 26 aligned with or adjacent to the coverage range or scan plane 13 of laser scanner 12 |
| 28 | light beam generated by visual light indicator 26 directed to the floor to indicate the coverage range or scan plane 13 of laser scanner 12 |

## Claims

1. A robot system, comprising:
   - a robot body (11);
   - a manipulator (10);
   - a control unit (20); and
   - at least one laser scanner (12);

   wherein the manipulator is mounted to the robot body;

   wherein the at least one laser scanner is mounted to the robot body;

   wherein the control unit is configured to move the manipulator relative to the robot body and/or control activation of the manipulator;

   wherein the control unit is configured to define at least one areal protective zone (14) at a periphery of the robot body, and wherein each areal protective zone of the at least one areal protective zone is defined at an angle between 45-90 degrees to the horizontal;

   wherein the control unit is configured to control the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one areal protective zone and acquire at least one sensor data for reflected laser radiation within at least one coverage range or scan plane (13) within the at least one 2D plane, wherein each 2D plane is coplanar with an areal protective zone, and wherein each laser scanner is configured to project laser radiation in a 2D plane coplanar with an areal protective zone and acquire sensor data for reflected laser radiation within a coverage range or scan plane within the 2D plane that is at least a significant proportion of the areal protective zone; and

   wherein the control unit is configured to trigger a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane.

2. Robot system according to claim 1, wherein each laser scanner of the at least one laser scanner is mounted on a swivel

mechanism (15), wherein the control unit is configured to control the swivel mechanism for each laser scanner to vary an angle of the projected laser radiation in the 2D plane at an angle between 45-90 degrees to the horizontal.

3. Robot system according to any of claims 1-2, wherein the control unit is configured to define a workspace (21) around the manipulator based on a work schedule of the manipulator, and wherein the control unit is configured to define each protective zone of the at least one areal protective zone at an angle between 45-90 degrees to the horizontal to maintain at least a clearance (23) distance between the at least one areal protective zone and the workspace.

4. Robot system according to claim 3, wherein the control unit is configured to define a size of the workspace dependent upon specific tasks within the work schedule.

5. Robot system according to any of claims 1-4, wherein the robot system comprises at least one visual indicator (26), wherein each visual indicator is configured to project visible light in a 2D plane, and wherein the control unit is configured to control one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes (27) aligned with and adjacent to the at least one coverage range or scan plane.

6. Robot system according to any of claims 1-5, wherein the robot system comprises at least one visual indicator (26), wherein each visual indicator is configured to project visible light in a 2D plane, and wherein the control unit is configured to control one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes (28) directed at the floor to indicate one or more locations of one or more outer extents of the at least one coverage range or scan plane.

7. Robot system according to any of claims 1-6, wherein the robot body is a vehicular robot, and wherein the control system is configured to control the robot body to move, and wherein when the robot body is moving, the control unit is configured to:

- define at least one horizontal areal protective zone (14) at a periphery of the robot body, and wherein each horizonal areal protective zone of the at least one horizontal areal protective zone is defined at an angle between -5-5 degrees to the horizontal;
- control the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one horizontal areal protective zone and acquire at least one sensor data for reflected laser radiation within at least one coverage range or scan plane (13) within the at least one 2D plane, wherein each 2D plane is coplanar with a horizontal areal protective zone, and wherein each laser scanner is configured to project laser radiation in a 2D plane coplanar with a horizontal areal protective zone and acquire sensor data for reflected laser radiation within a coverage range or scan plane within the 2D plane that is at least a significant proportion of the horizontal areal protective zone; and
- trigger a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane coplanar with the at least one horizontal areal protective zone.

8. A method of controlling a robot, wherein a manipulator is mounted to a robot body of the robot and a control unit is configured to move the manipulator relative to the robot body and/or control activation of the manipulator, wherein at least one laser scanner is mounted to the robot body, and wherein the method comprises:
- defining, by the control unit, at least one areal protective zone at a periphery of the robot body, and wherein each areal protective zone of the at least one areal protective zone is defined at an angle between 45-90 degrees to the horizontal;
- controlling, by the control unit, the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one areal protective zone, wherein each 2D plane is coplanar with an areal protective zone, and wherein each laser scanner is configured to project laser radiation in a 2D plane coplanar with an areal protective zone;
- acquiring, by the at least one laser scanner, at least one sensor data for reflected laser radiation within at least one coverage range

or scan plane within the at least one 2D plane if an object is present within a coverage range or scan plane of the at least one coverage range or scan plane, and wherein each coverage range or scan plane within a 2D plane is at least a significant proportion of the associated areal protective zone; and

- triggering, by the control unit, a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane.

9. Method according to claim 8, wherein each laser scanner of the at least one laser scanner is mounted on a swivel mechanism (15), and wherein the method comprises:

- controlling, by the control unit, the swivel mechanism for each laser scanner to vary an angle of the projected laser radiation in the 2D plane at an angle between 45-90 degrees to the horizontal.

10. Method according to any of claims 8-9, wherein the method comprises:

- defining, by the control unit, a workspace around the manipulator based on a work schedule of the manipulator; and

- defining, by the control unit, each protective zone of the at least one areal protective zone at an angle between 45-90 degrees to the horizontal to maintain at least a clearance distance between the at least one areal protective zone and the workspace.

11. Method according to claim 10, wherein the method comprises:

- defining, by the control unit, a size of the workspace dependent upon specific tasks within the work schedule.

12. Method according any of claims 8-11, wherein at least one visual indicator is mounted to the robot, wherein each visual indicator is configured to project visible light in a 2D plane, and wherein the method comprises:

- controlling, by the control unit, one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes aligned with and adjacent to the at least one coverage range or scan plane.

13. Method according any of claims 8-12, wherein at least one visual indicator is mounted to the robot, wherein each visual indicator is configured to project visible light in a 2D plane, and wherein the method comprises:

- controlling, by the control unit, one or more visual indicators of the at least one visual indicator to project visible light in one or more 2D planes directed at the floor to indicate at one or more locations of one or more outer extents of the at least one coverage range or scan plane.

14. Method according to any of claims 8-13, wherein the robot is a vehicular robot, and wherein when the robot is moving the method comprises:

- defining, by the control unit, at least one horizontal areal protective zone at a periphery of the robot body, and wherein each horizonal areal protective zone of the at least one horizontal areal protective zone is defined at an angle between -5-5 degrees to the horizontal;
- controlling, by the control unit, the at least one laser scanner to project laser radiation in at least one 2D plane that is coplanar with the at least one horizontal areal protective zone, wherein each 2D plane is coplanar with a horizontal areal protective zone, and wherein each laser scanner is configured to project laser radiation in a 2D plane coplanar with a horizontal areal protective zone;
- acquiring, by the at least one laser scanner, at least one sensor data for reflected laser radiation within at least one coverage range or scan plane within the at least one 2D plane if an object is present within a coverage range or scan plane of the at least one coverage range or scan plane, and wherein each coverage range or scan plane within a 2D plane is at least a significant proportion of the associated horizontal areal protective zone; and
- triggering, by the control unit, a safety response upon acquisition of sensor data for reflected laser radiation within the at least one coverage range or scan plane within the at least one 2D plane coplanar with the at least one horizontal areal protective zone.

15. A computer program element for controlling an apparatus according to any of claims 1-7 which when executed by a processor is configured to carry out the method of any of claims 8-14.

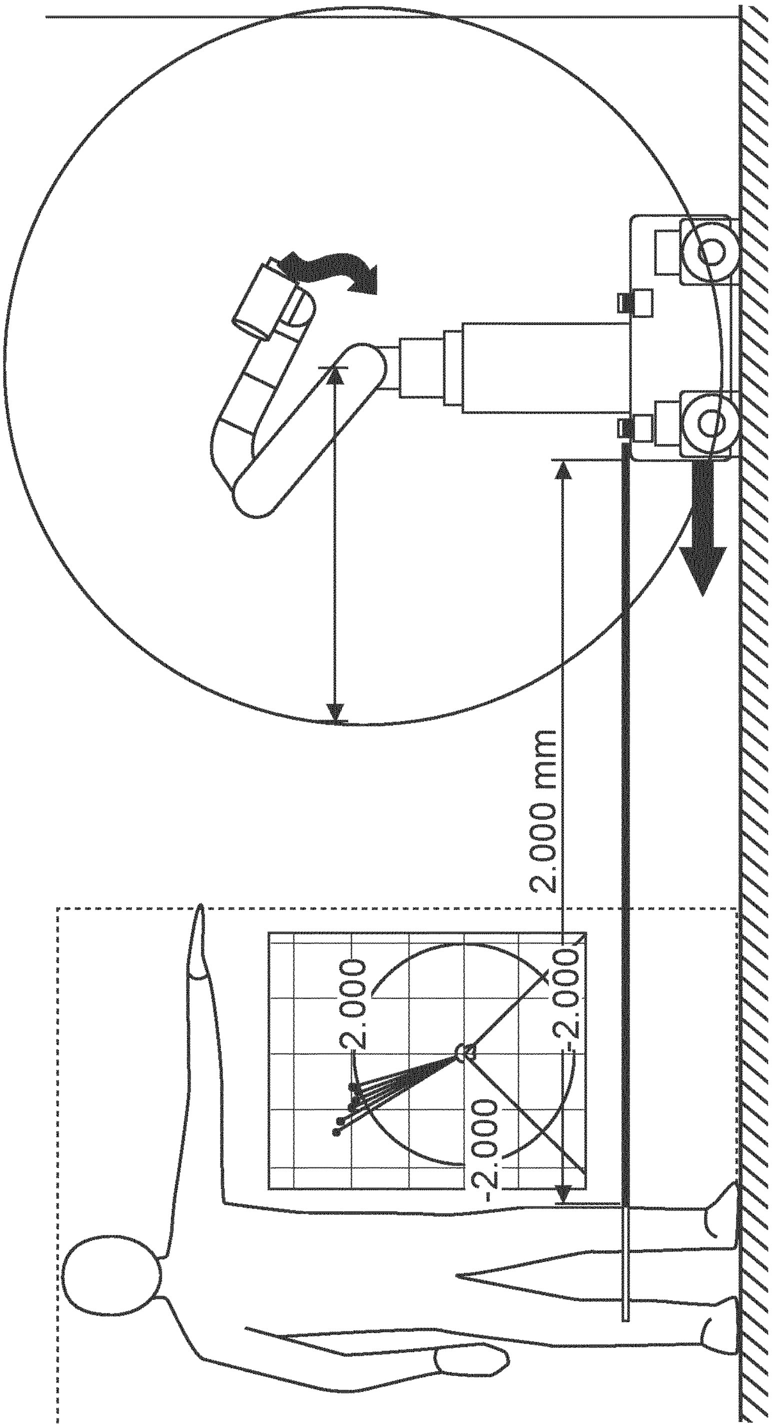


Fig. 1

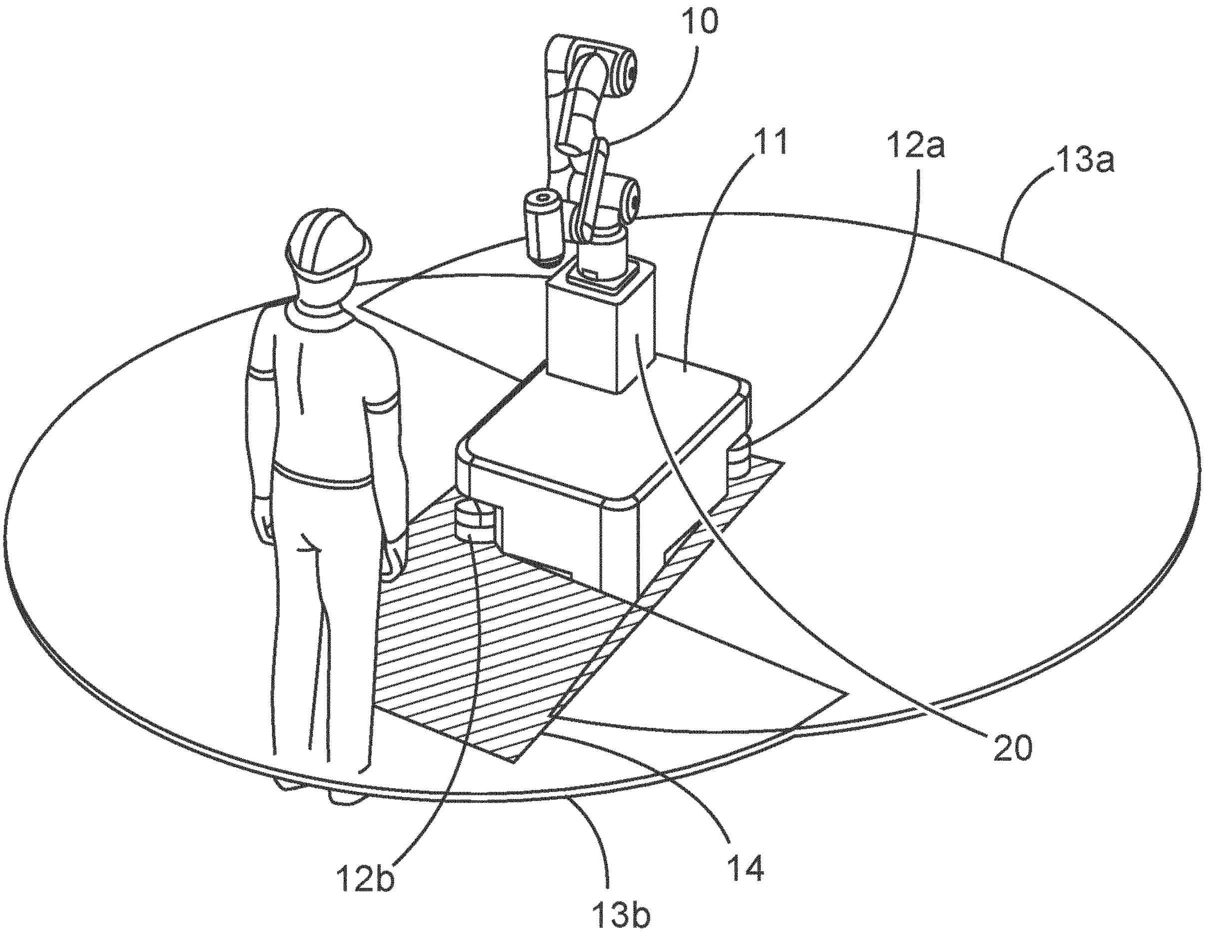


Fig. 2

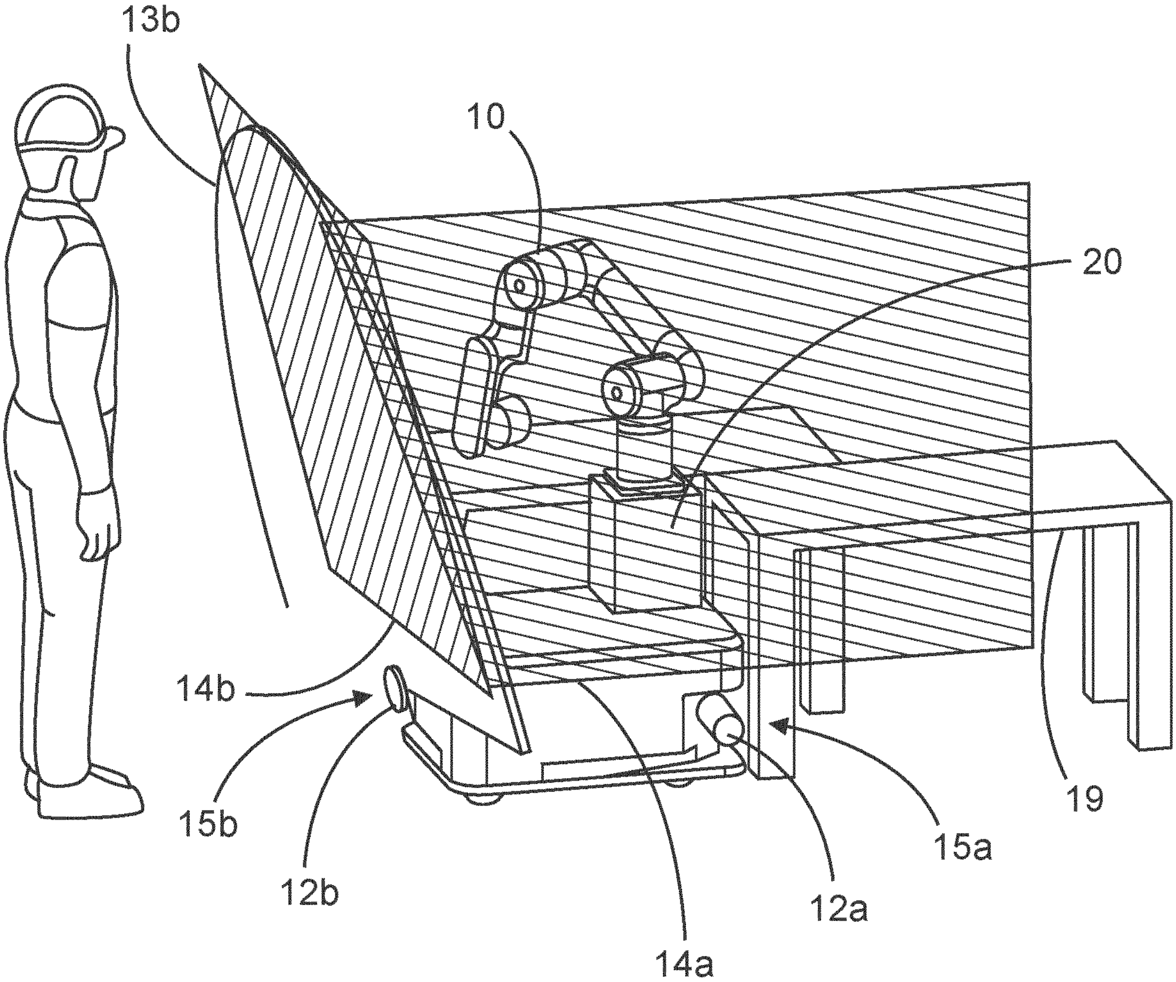


Fig. 3

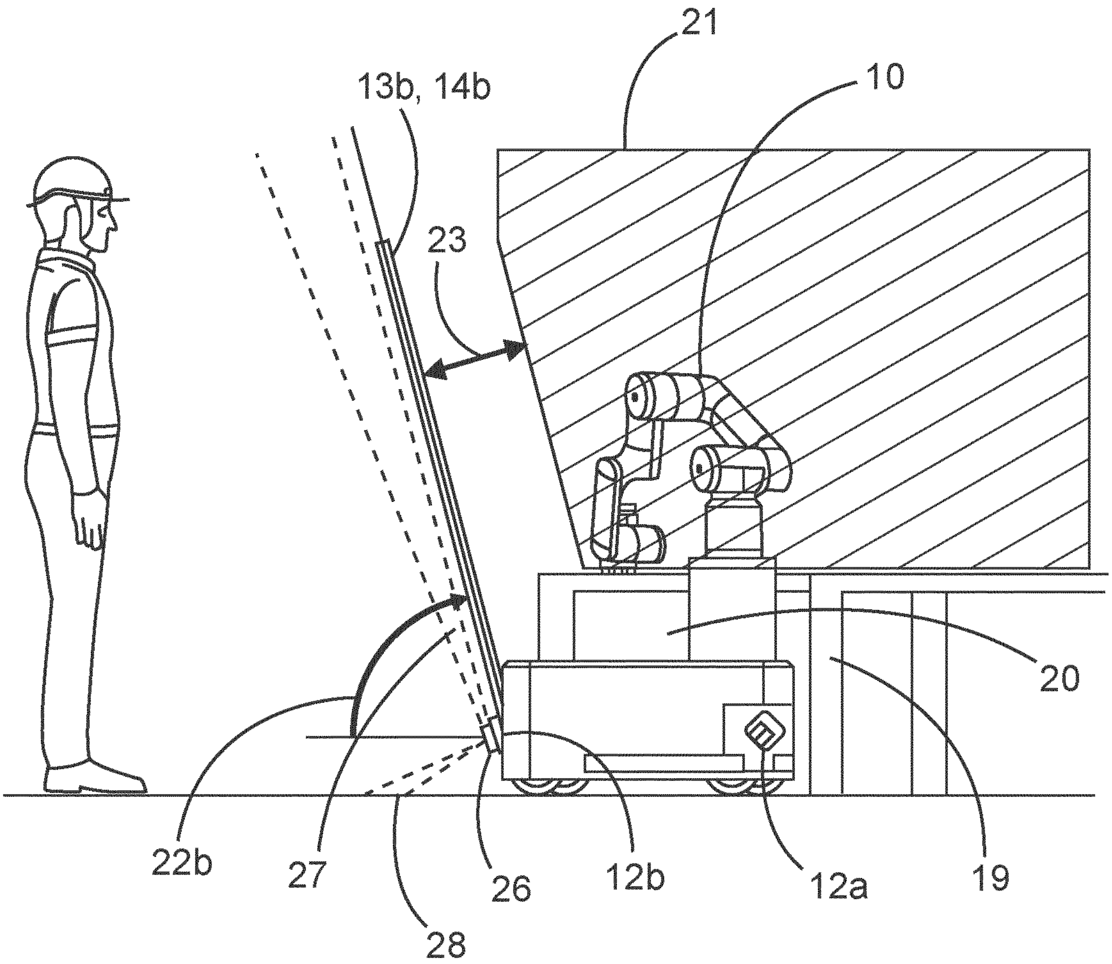


Fig. 4

# INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2023/066253

**A. CLASSIFICATION OF SUBJECT MATTER**

INV. B25J9/16 B25J19/02 B25J19/06 F16P3/14 G05D1/02

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)

B25J G05B F16P G05D

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

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | DE 10 2010 046327 B4 (KUKA ROBOTER GMBH [DE]) 28 October 2021 (2021-10-28)<br>the whole document<br>----- | 1-4, 8-11,15 |
| X | US 2016/059411 A1 (RICHTER STEFAN [DE] ET AL) 3 March 2016 (2016-03-03)<br>the whole document<br>----- | 1-15 |
| A | US 2018/326586 A1 (MAGNANIMO VITO [DE] ET AL) 15 November 2018 (2018-11-15)<br>the whole document<br>----- | 1-15 |

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 14 December 2023 | 04/01/2024 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Marinica, Raluca |

1

# INTERNATIONAL SEARCH REPORT

**Information on patent family members**

International application No
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