



- (51) **International Patent Classification:**
B25J 9/16 (2006.01)
- (21) **International Application Number:**
PCT/EP2013/054032
- (22) **International Filing Date:**
28 February 2013 (28.02.2013)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
201210583950.2 28 December 2012 (28.12.2012) CN
- (71) **Applicant: ABB TECHNOLOGY LTD** [CH/CH]; Affolternstrasse 44, CH-8050 Zürich (CH).
- (72) **Inventors; and**
- (71) **Applicants (for US only): ZAHRAI, Said** [SE/CN]; Room 2602, Yanlord Town Building 17, Dingxiang Road 1599, Pudong District, Shanghai, 200135 (CN). **MATTHIAS, Björn** [DE/DE]; Zeuterner Straße 4, 76669 Bad Schönborn (DE).
- (74) **Agent: ZIMMERMANN & PARTNER;** Josephspitalstr. 15, 80331 München (DE).

(81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) **Title:** METHOD AND APPARATUS FOR REDUCTION OF CO-WORKER'S INJURY

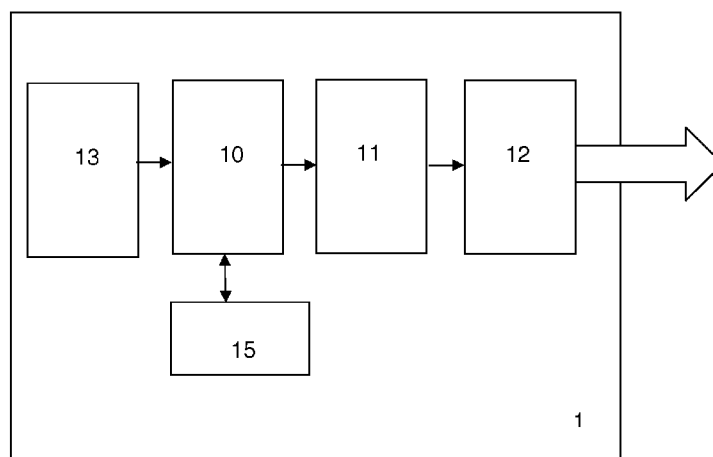


Figure 1

(57) **Abstract:** It is provided a method and an apparatus for reduction of a potential injury of a co-worker resulting from an intersection by a hazardous zone of a work piece held by a robot and a body part of the co-worker in a cell accommodating the robot. The method includes steps of: selecting a first, a second, a third and a fourth value for a first, a second, a third and a fourth variable, wherein the first variable represents a relative velocity between the hazardous zone of the work piece and the body part of the co-worker, the second variable represents a degree of an inertia of the moving part of the robot and the work piece, the third variable represents a degree of a vulnerability of the body part of the co-worker, and the fourth variable represents a degree of a hazardousness for the hazardous zone of the work piece; and predicting a degree of a potential hazard resulting from the intersection of the hazardous zone of the work piece and the body part of the co-worker according to the first, second, third and fourth variables. It is helpful to produce data to estimate the injury for a well-defined intersection at a given relative speed in vector form between a human body part and a work piece of elementary shape held by a robot in motion.



Method and Apparatus for Reduction of Co-worker's Injury

Technical Field

5 The present disclosure relates to the field of method for reduction of co-worker's injury from work piece held by a robot, and more particularly to the field of integrated safe guard for injuring co-workers by a work piece held by robot. The present disclosure also relates to an apparatus for reduction of a potential injury of a co-worker, in particular, it relates to an apparatus for reduction of a potential injury resulting from an intersection by a
10 hazardous zone of a work piece held by a robot and a body part of the co-worker in a cell accommodating the robot.

Background Art

15 A robot itself can be made safe in different ways. However, the safe operation of a collaborative machine does not involve the robot itself only, but also the work-piece, the cell and environment the robot is working in. The robot can be called as safe if it will not hurt its human collaborators in any possible condition.

Safety assessed collaborative machines normally do not include assessment of potential hazard from the work piece, the cell and the environment the robot is working in. Thus, it
20 is hard for the integrator to foresee if the collaborative machine meets the safety requirements of the end user.

Brief Summary of the Invention

25 In view of the above, according to one embodiment, the invention provides a method for reduction of a potential injury of a co-worker resulting from an intersection by a hazardous zone of a work piece held by a robot and a body part of the co-worker in a cell accommodating the robot, including steps of: selecting a first, a second, a third and a fourth value for a first, a second, a third and a fourth variable, wherein the first variable represents a relative velocity between the hazardous zone of the work piece and the body part of the
30 co-worker, the second variable represents a degree of an inertia of the moving part of the robot and the work piece, the third variable represents a degree of a vulnerability of the body part of the co-worker, and the fourth variable represents a degree of a hazardousness for the hazardous zone of the work piece; and predicting a degree of a potential hazard resulting from the intersection of the hazardous zone of the work piece and the body part of
35 the co-worker according to the first, second, third and fourth variables. It is helpful to produce data to estimate the injury for a well-defined intersection at a given relative speed in vector form between a human body part and a work piece of elementary shape held by a robot in motion.

40 According to another embodiment of the invention, an apparatus is provided for reduction of a potential injury of a co-worker resulting from an intersection by a hazardous zone of a work piece held by a robot and a body part of the co-worker in a cell accommodating the robot, including: a selection part, being adapted for selecting a first, a second, a third and a fourth value for a first, a second, a third and a fourth variable, wherein the first variable represents a relative velocity between the hazardous zone of the work piece and the body
45 part of the co-worker, the second variable represents a degree of an inertia of the moving

part of the robot and work piece, the third variable represents a degree of a vulnerability of the body part of the co-worker, and the fourth variable represents a degree of a hazardousness for the hazardous zone of the work piece; and a prediction part, being adapted for predicting a degree of a potential hazard resulting from the intersection of the hazardous zone of the work piece and the body part of the co-worker according to the first, second, third and fourth variables.

It is helpful to produce data to estimate the injury for a well-defined intersection at a given relative speed in vector form between a human body part and a work piece of elementary shape held by a robot in motion.

The invention is also directed to an apparatus for carrying out the disclosed methods and including apparatus parts for performing each described method steps. These method steps may be performed by way of hardware components, a computer programmed by appropriate software, by any combination of the two or in any other manner. Furthermore, the invention is also directed to methods by which the described apparatus operates. It includes method steps for carrying out every function of the apparatus.

Further embodiments, aspects, details and advantages are evident from the dependent claims, the description, and the drawings.

Brief Description of the Drawings

The subject matter of the invention will be explained in more detail in the following text with reference to exemplary embodiments which are illustrated in the drawings, in which:

Figure 1 illustrates a block diagram that shows the apparatus for reduction of the potential injury of a co-worker according to an embodiment of present invention; and

Figure 2 shows a flow chart for a method for reduction of a potential injury of a co-worker resulting from an intersection by a hazardous zone of a work piece held by a robot and a body part of the co-worker in a cell accommodating the robot according to the embodiment of figure 1.

The reference symbols used in the drawings, and their meanings, are listed in summary form in the list of reference symbols. In principle, identical parts are provided with the same reference symbols in the figures.

Detailed description of embodiments of the Invention

As the robot holds a work piece and moves it around, the geometrical and physical properties of the work piece directly influence the potential risk the robot has to hurt or injure the co-workers. As an example, if the robot is holding a soft ball, it has a lower risk for injury of the co-workers in comparison with the case when the robot is holding a knife. In case a hazardous object is held, the integrator must evaluate the risks related to the work piece itself and try to eliminate them or reduce them to an acceptable risk level. It follows that the degree of potential injury of a co-worker resulting from a collision between a robot-held work piece and the co-worker is at least contributed by the shape of the hazardous zone of the work piece, the degree of vulnerability of the body part of the co-worker in collision with the work object, the relative velocity between the hazardous zone of the work piece and the body part, and the inertia of the moving part of the robot together with the work object. If the above factors are recognized and evaluated, then the potential injury of co-worker could be predicted and estimated. Based on the prediction of the

potential injury and its degree, off-line the robot program and the cell design could be revised for avoidance of the potential injury or on-line the robot controller could control the robot to move in a safe route.

Figure 1 illustrates a block diagram that shows the apparatus for reduction of the potential injury of a co-worker according to an embodiment of present invention. As shown in figure 1, the apparatus 1 for reduction of a potential injury of a co-worker includes a selection part 10 and a prediction part 11. The potential injury of the co-worker may result from an intersection by a hazardous zone of a work piece held by a robot and a body part of the co-worker in a cell accommodating the robot. The apparatus 1 may be implemented by a data processing system, such as a personal computer and/or a robot controller, and the parts such as the selection part 10 and the prediction part 11 may be implemented by means of modules of data processing system.

The selection part 10, receives inputs, based on which, it selects a first, a second, a third and a fourth value for a first, a second, a third and a fourth variable, wherein the first variable represents a relative velocity between the hazardous zone of the work piece and the body part of the co-worker, the second variable represents a degree of inertia of the moving part of the robot together with the work piece, the third variable represents the degree of vulnerability of the body part of the co-worker in collision with the work piece, and the fourth variable represents degree of hazardousness for the hazardous zone of the work piece that collides with the co-worker. By having the selection part 10, it is possible for the apparatus 1 to have valid values for the factors contributing to the potential injury. Such values are correlated to experimental or simulation data and justified by prior experiment results.

The first, second, third and fourth values for the first, second, third and fourth variables may be selected from a database which uses a data structure storing possible values for the mentioned variables and the corresponding index for the level of damage a collision can make for each of the possible combination. The resulting values are quantified according to the data from experiment or simulation under various scenarios.

In the following text a possible procedure for creating the necessary data table to estimate and predict the level of potential injury and the damage a collision between the moving work piece and a part of the co-worker's body is described as following steps a to f. During these steps, the variables with impact on the injury level are identified and their influence on the final level of injury is estimated by means of experiments.

a. Definition of the potential injury index

At the starting point, a method to compare the severity of the injury must be defined. To do that, the injuries are ordered that might happen and are of interest in the analysis in an ordered table like below:

Order	Type of injury
0	No bad feeling
1	Uncomfortable pain
2	Needs medical care
3	Bleeding badly

4	Needs to be away from work
5	Unrecoverable injury
6	Fatal

Table I

The type of injuries above can be different depending on the case of interest. It is important that the order will be correctly chosen, so that an injury of order n is more severe than one of order $n-1$. Then, an exponential injury index, DI, is associated to each level of the injuries above by simply having a number, say M , to power of the order of the injury. Here, we simply choose M to be equal to 2 and we will have the following values:

Order	Type of injury	DI
0	No bad feeling	1
1	Uncomfortable pain	2
2	Needs medical care	4
3	Bleeding badly	8
4	Needs to be away from work	16
5	Unrecoverable injury	32
6	Fatal	64

Table I

The exact value of M does not have any impact except that $DI(\text{Order } i) = M \cdot DI(\text{Order } i-1)$.

- 10 The exponential ordering is intentionally chosen so that the possible injury can be moved from one class to the next by simply multiplying the related DI by M .

b. Quantification of the geometry of the hazardous zone of the work

- 15 In a general case, one might expect that a complex structure would cause danger of different levels from different angles and directions. As a possible method, it is proposed to decompose the total exposed danger into risks for injury coming from different parts of the work piece for the actual case of motion. Once the possible injury from each substructure of the work piece under the describes circumstances is found, the highest value can be taken as that representative for the work piece and specific motion under analysis. The complex geometry can be decomposed to elementary geometrical parts that can be identified, analyzed and parameterized. This can also be done in several different ways, of which one proposal can be the one shown in the following table.

Order	Type of geometry	Main parameters	Directions
1	Tip	Minimum curvature, Depth	Pointing direction, Any other two perpendicular to first direction
2	Edge	Minimum curvature,	Sharp direction,

		Length, Depth	Parallel to the edge, Perpendicular to the first two
3	Sphere	Minimum curvature	Perpendicular to the surface, Any other two perpendicular to first direction
4	Plane surface	Diameter	Perpendicular to the surface

Table II

In Table II, the hazardous elementary geometries are classified into four groups and for each group important parameters and important directions are defined. For example, a knife can be considered as a tip in one direction, as an edge in another direction and as a surface in the third direction. For each of these, important directions are defined. The directions are defined so that the first direction is the main impact direction and if the relative velocity in the main direction is less or equal to zero, no impact will occur and therefore no injury can be expected.

c. Quantification of impact of the moving part of the robot

For testing or simulation of the impact, one has to have a mechanical description of the moving part of the robot. Due to the complexities of the kinematic of the robot, there can be configurations that are more dangerous than others. As the simulation or test solely concerns an impact, a simple inertia, or mass model will be sufficient. However, the test needs to be done for different inertia or masses so that all configurations can be covered.

	Configuration	Equivalent mass
1	Robot in zero position, axis 3 moving	2kg
2	Robot in zero position, axis 1 moving	7kg
3	Robot in stretch position, axis 1 moving	10kg

Table III

d. Quantification of vulnerability of body parts

The sensitive parts of the body need to be counted and put in an increasing order of vulnerability, for example as in the table below.

Order	Body part
1	Hands
2	Chest
3	Head

Table IV

Once the important body parts are selected, one should provide means to simulate, model or estimate the vulnerability of each body part. For example, test dummies can be used for physical tests or numerical simulation models can be used for numerical tests.

The worst case of impact will be when the human body cannot move back. As risk should concern the worst possible case, here, the focus will be made on the case that the model of the human body is kept fixed and will be hit by the object.

e. Estimation of damage index, DI, by means of experiments

For each body part and each of elementary shapes of hazardous zone one needs to make several objects with variations of the parameters as noted in Table II. If the actual robot is available, the object can be connected to the robot. If the robot is not available, or the data is expected to be used as generic for all robots, the object must be connected to a mass so that moving part configuration can be simulated. The mass should of course be varied so that all robot configurations can be simulated. The mass must be connected to a machine that can be moved in a controlled manner. After mounting the object on the robot or the object and the mass to that machine, a coordinate system can be defined so that the direction one will be in the main direction of the object, as shown in Table I, direction 2 will be aligned with the second direction and direction 3 with the third direction. For those cases, like the tip, where the second and third directions are equal, direction 2 and 3 can be chosen freely perpendicular to direction 1.

The speed will be varied in directions 1, 2 and 3 from the minimum value to maximum value with sufficient number of steps between and the impact between the hazardous object and body part is simulated. For each case, the damage is evaluated according to the table described above and the degree of damage, the damage index DI will be determined for each case. This value will be stored in the database.

In terms of the above definitions, one can perform tests or simulations in order to find the degree of injury for each of the possible cases above and store the result in a table for later reference. As it concerns about the degree of injury to human body, a direct test on the real person cannot be an alternative. Instead, one might make a model of the body part and allow the impact occur on that. The degree of injury can be evaluated either by making direct measurements of pressure and forces or by studying of the changes on the model. The physical test will follow a procedure as described below.

f. Prediction of the degree of injury and damage due to collision between the work piece and a part of human body

The five above steps need to be performed only once. When the table is available the results can be used for predictions or control of robot in the following way. The integrator designs the cell and thereby provides necessary program for the robot. As the work object is defined, the program defines how it will be moved around by the robot. Likewise, the geometry is decomposed into a number of elementary geometries and in each direction, the most dangerous one is considered. By an assessment of the cell design, the integrator associates information about where in the cell there will be possibilities of collision between robot and a well-defined part of human body and in the worst case, how the part of the human body could move.

When the work piece passes areas with possibility of collision, first the relative velocity is calculated. The inertia of the moving part of the robot and the work piece are known, the geometry is already defined as an elementary geometry with its respective parameters. These three pieces of information, together with knowledge about what part of the body will collide, give necessary information for a table lookup from the above database and

thereby the degree of injury can be found. At this stage, the integrator can, if needed, make new arrangements so that the degree of injury is lowered to the requested value.

As an alternative approach, the robot controller can include the above mentioned database and make an analysis before moving the robot. If the degree of possible injury is too high,
 5 the robot can take actions like reducing the speed, changing the direction of the work piece or use a cover over the dangerous part of the work piece.

This will be done by the mentioned apparatus as follows. The prediction part 11 is adapted for predicting the degree of a potential hazard resulting from the intersection of the hazardous zone of the work piece and the body part of the co-worker according to the first,
 10 second, third and fourth variables that are selected by the selection part 10. For each case, the injury is predicted according to the tables described above and the degree of injury, the injury index DI will be determined for each case.

In particular for example, the selection part 10 selects the value "Edge" and "Sharp direction, Parallel to the edge, Perpendicular to the first two" in Table I, "robot in zero
 15 position axis 3 moving, 2Kg" in Table II, "Head" in Table III. After that, once the relative speed is known, the prediction part 11 predicts the related damage index DI for that particular speed and the choices above.

By having the apparatus as above, it allows us to produce data to estimate the injury D for a well-defined intersection at a given relative speed in vector form between a human body
 20 part and a work piece of elementary shape held by a robot in motion. If that is within the allowed range, the motion can be assumed to be safe otherwise actions need to be taken to reduce the level of injury. In consideration of this, the apparatus 1 may further include a path planning part 12 being adapted for planning the movements of the robot on the basis of the degree of a potential hazard. The path planning part 12 may plan a robot path, for
 25 which if the hazardous degree is beyond the allowed range. In that case, the speed of movement of the robot will be limited, the robot will hold the work piece in a safe orientation, and/or the robot covers the work piece by a protector for protection of the co-worker from the work piece.

Alternatively, the apparatus 1 may further include a control part being adapted for
 30 controlling the movements of the robot on the basis of the degree of the potential hazard. When the robot is running, the control part may control the robot operate in a way that if the hazardous degree is beyond the allowed range, the speed of movement of the robot is limited, the robot holds the work piece in a safe orientation, and/or the robot covers the work piece by a protector for protection of the co-worker from the work piece.

The procedure above might lead to a large number of data coming from equally large
 35 number of experiments. In some cases, one might make simplifications and after validations reduce the number of experiments to be carried out. Here, some examples are given. Validations are needed before applying them.

To reduce the number of cases and the size of the table, one can argue that the most
 40 important impact is when the relative motion is in first direction and that motion in the other directions will have a worsening impact. That will give

$$DI = DI^1 \times DI^2 \times DI^3$$

Further, the damage from the main impact is only depending on the relative speed in the first direction

$$DI^1 = DI^1(v_1),$$

45 and that the motion in the other direction is not changing the level of damage unless the speed is larger than a value, say v_0 , and otherwise it makes the damage one class more

severe, i.e.

if ($v < v_0$) : $DI^2(v) = DI^3(v) = 1$
otherwise : $DI^2(v) = DI^3(v) = M = 2$.

This will reduce the size of the table enormously as speed needs to be changed in one direction only. In the same way, one might find that the damage to hand, chest and head are similar, but they become more and more severe. In that case, it would be enough to find the damage fortissue and afterwards rescale the damage to more severe or less severe. How much it should be changed can be found for speed only. Although the assumptions need testing for validation, still they eliminate three dimensions from 6 to 3, which is a very strong simplification of the work.

The apparatus 1 may further include a recognition part 13 being adapted for recognizing the relative velocity between the hazardous zone of the work piece and the body part of the co-worker, the inertia of the moving part of the robot, the degree of the vulnerability of the body part of the co-worker, and the degree of the hazardousness for the geometrical and physical properties of the hazardous zone of the work piece. The recognition part 13 may recognize the relative speed between the hazardous zone of the work piece and the body part of the co-worker in consideration of the robot program and the cell design. The recognition part 13 may recognize the values for the inertia of the moving part of the robot, the degree of the vulnerability of the body part of the co-worker, and the degree of the hazardousness for the geometrical and physical properties of the hazardous zone of the work piece based on an estimation of an integrator.

The apparatus 1 may further include a memory part 14 being adapted for storing a table comprising a multiple of the first values, a multiple of the second values, a multiple of the third values, and a multiple of the fourth values, for example Tables I through V, and the selection part 10 being further adapted for based on the recognition selecting the first, second, third and fourth value for the first, the second, the third and the fourth variable.

Figure 2 shows a flow chart for a method for reduction of a potential injury of a co-worker resulting from an intersection by a hazardous zone of a work piece held by a robot and a body part of the co-worker in a cell accommodating the robot according to the embodiment of figure 1. In step S200, selecting a first, a second, a third and a fourth value for a first, a second, a third and a fourth variable, wherein the first variable represents a relative velocity between the hazardous zone of the work piece and the body part of the co-worker, the second variable represents a degree of an inertia of the robot, the third variable represents a degree of a vulnerability of the body part of the co-worker, and the fourth variable represents a degree of a hazardousness for the hazardous zone of the work piece; next in step S201, predicting a degree of a potential hazard resulting from the intersection of the hazardous zone of the work piece and the body part of the co-worker according to the first, second, third and fourth variables. By having the method as above, it allows us to produce data to estimate the injury D for a well-defined intersection at a given relative speed in vector form between a human body part and a work piece of elementary shape held by a robot in motion.

If that is within the allowed range, the motion can be assumed to be safe otherwise actions need to be taken to reduce the level of injury. Thus, the method may further include step S202, planning the movements of the robot on the basis of the degree of a potential hazard; or alternatively step, controlling the movements of the robot on the basis of the degree of the potential hazard. In particular for example, either for step S202 or step S203, where the speed of movement of the robot is limited, the movement of the robot includes holding the

work piece in a safe orientation, or the movement of the robot includes covering the work piece by a protector for protection of the co-worker from the work piece.

5 The method may further include a step S203, recognizing the relative velocity between the hazardous zone of the work piece and the body part of the co-worker, the inertia of the moving part of the robot, the degree of the vulnerability of the body part of the co-worker, and the degree of the hazardousness for the geometrical and physical properties of the hazardous zone of the work piece. Based on the recognition, selecting the first, second, third and fourth value for the first, the second, the third and the fourth variable from a table comprising a multiple of the first values, a multiple of the second values, a multiple of the
10 third values, and a multiple of the fourth values. For example in particular, the first value is recognized in consideration of the robot program and the cell design.

Though the present invention has been described on the basis of some embodiments, those skilled in the art should appreciate that those embodiments should by no way limit the scope of the present invention. Without departing from the spirit and concept of the present
15 invention, any variations and modifications to the embodiments should be within the apprehension of those with ordinary knowledge and skills in the art, and therefore fall in the scope of the present invention which is defined by the accompanied claims.

CLAIMS

1. A method for reduction of a potential injury of a co-worker resulting from an intersection by a hazardous zone of a work piece held by a robot and a body part of the co-worker in a cell accommodating the robot, including:

selecting a first, a second, a third and a fourth value for a first, a second, a third and a fourth variable, wherein the first variable represents a relative velocity between the hazardous zone of the work piece and the body part of the co-worker, the second variable represents a degree of an inertia of the moving part of the robot and the work piece, the third variable represents a degree of a vulnerability of the body part of the co-worker, and the fourth variable represents a degree of a hazardousness for the hazardous zone of the work piece; and

predicting a degree of a potential hazard resulting from the intersection of the hazardous zone of the work piece and the body part of the co-worker according to the first, second, third and fourth variables.

2. The method according to claim 1, wherein:

the first variable represents the relative velocity between the hazardous zone of the work piece and the body part of the co-worker in one main direction.

3. The method according to claim 1 or 2, further including:

planning the movements of the robot on the basis of the degree of a potential hazard.

4. The method according to claim 1, 2 or 3, further including :

controlling the movements of the robot on the basis of the degree of the potential hazard.

5. The method according to claim 3 or 4, wherein:

the speed of the movement of the robot is limited.

6. The method according to any of claims 3 to 5, wherein:

the movement of the robot includes holding the work piece in a safe orientation.

7. The method according to any of claims 3 to 6, wherein:

the movement of the robot includes covering the work piece by a protector for protection of the co-worker from the work piece.

8. The method according to any of the preceding claims, wherein:

selecting the first, second, third and fourth value for the first, the second, the third and the fourth variable from a table comprising a multiple of the first values, a multiple of the second values, a multiple of the third values, and a multiple of the fourth values, based on recognition of the relative velocity between the hazardous zone of the work piece and the body part of the co-worker, the inertia of the moving part of the robot, the degree of the vulnerability of the body part of the co-worker, and the degree of the hazardousness for the geometrical and physical properties of the hazardous zone of the work piece.

9. The method according to claim 8, further comprising:

recognizing the first value in consideration of the robot speed measured or calculated based on the robot program, the cell design and the body part movement speed set by an integrator;

recognizing the second, third and fourth variables based on inputs by a programmer .

10. An apparatus for reduction of a potential injury of a co-worker resulting from an intersection by a hazardous zone of a work piece held by a robot and a body part of the co-worker in a cell accommodating the robot, including:

- 5 a selection part, being adapted for selecting a first, a second, a third and a fourth value for a first, a second, a third and a fourth variable, wherein the first variable represents a relative velocity between the hazardous zone of the work piece and the body part of the co-worker, the second variable represents a degree of an inertia of the moving part of the robot and work piece, the third variable represents a degree of a vulnerability of the body part of the co-worker, and the fourth variable represents a degree of a hazardousness for the hazardous zone of the work piece; and

a prediction part, being adapted for predicting a degree of a potential hazard resulting from the intersection of the hazardous zone of the work piece and the body part of the co-worker according to the first, second, third and fourth variables.

- 15 11. The apparatus according to claim 10, wherein:

the first variable represents the relative velocity between the hazardous zone of the work piece and the body part of the co-worker in one main direction.

12. The apparatus according to claim 10 or 11, further including:

- 20 a path planning part, being adapted for planning the movements of the robot on the basis of the degree of a potential hazard.

13. The apparatus according to claim 10, 11 or 12, further including:

a control part, being adapted for controlling the movements of the robot on the basis of the degree of the potential hazard.

14. The apparatus according to claim 12 or 13, wherein:

- 25 the speed of movement of the robot is limited so that the damage due to a collision is below the set limit.

15. The apparatus according to any of claims 12 to 14, wherein:

the movement of the robot includes holding the work piece in a safe orientation.

16. The apparatus according to any of claims 12 or 15, wherein:

- 30 the movement of the robot includes covering the work piece by a protector for protection of the co-worker from the work piece.

17. The apparatus according to any one of claims 10 to 16, further including:

- 35 a recognition part, being adapted for recognizing the relative velocity between the hazardous zone of the work piece and the body part of the co-worker, the inertia of the moving part of the robot, the degree of the vulnerability of the body part of the co-worker, and the degree of the hazardousness for the geometrical and physical properties of the hazardous zone of the work piece; and

- 40 a memory part, being adapted for storing a table comprising a multiple of the first values, a multiple of the second values, a multiple of the third values, and a multiple of the fourth values;

wherein:

the selection part is further adapted for, based on the recognition, selecting the first, second, third and fourth value for the first, the second, the third and the fourth variable from the table.

18. The apparatus according to claim 17, wherein:

- 5 the recognition part is further adapted for recognizing the first value in consideration of the robot speed measured or calculated based on the robot program, the cell design and the body part movement speed set by an integrator, and wherein recognizing the second, third and fourth variables is based on inputs by a programmer.

10

15

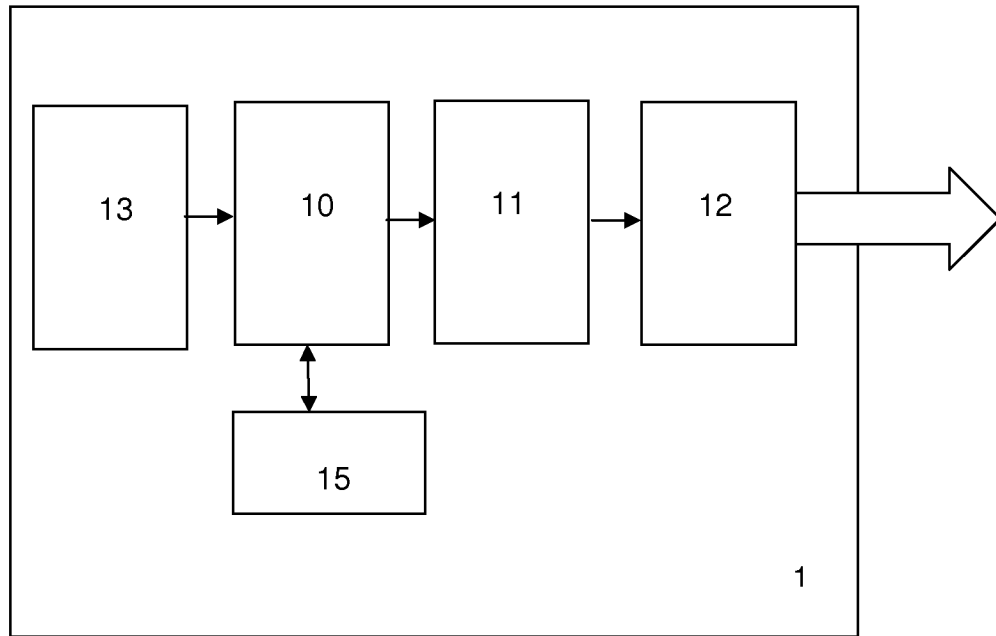


Figure 1

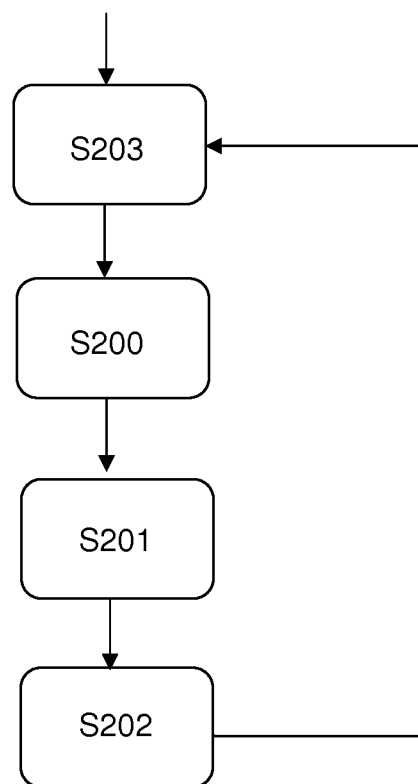


Figure 2

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2013/054032

A. CLASSIFICATION OF SUBJECT MATTER

INV. B25J9/16

ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B25J

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

Electronic data base consulted during the international search (name of data base and, where 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	WO 2010/063319 A1 (ABB RESEARCH LTD [CH]; KOCK SOENKE [SE]) 10 June 2010 (2010-06-10)	1-5, 8-14, 17, 18
Y	page 1, line 1 - page 8, line 17 page 9, line 30 - page 11, line 24	6, 7, 15, 16
Y	----- US 2008/161970 A1 (ADACHI YUJI [JP] ET AL) 3 July 2008 (2008-07-03)	7, 16
A	paragraphs [0096] - [0102] paragraph [0107]	1-6, 8-15, 17, 18
Y	----- US 2010/087955 A1 (TSUSAKA YUKO [JP] ET AL) 8 April 2010 (2010-04-08)	6, 15
A	paragraphs [0038], [0039], [0154] - [0161], [0165], [0174] - [0187], [0194] - [0199], [0249] - [0253], [0270] - [0274] ----- -/-	1-5, 7-14, 16-18



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

24 April 2013

Date of mailing of the international search report

24/05/2013

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Prokopiou, Platon

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/054032

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009/105880 A1 (OKAZAKI YASUNAO [JP]) 23 April 2009 (2009-04-23) paragraphs [0005] - [0008], [0012], [0013], [0057] - [0061], [0069] - [0070], [0073] - [0078], [0081] - [0085], [0098] paragraphs [0135] - [0139], [0155] - [0161] -----	1-18
A	US 2006/049939 A1 (HABERER MANFRED [DE] ET AL) 9 March 2006 (2006-03-09) paragraphs [0027] - [0043] -----	1-18
A	WO 2012/076029 A1 (ABB AG [DE]; MATTHIAS BJORN [DE]; LUNDBERG IVAN [SE]; VITTOR TIMOTHY []) 14 June 2012 (2012-06-14) page 2, line 12 - page 5, line 10 page 7, line 17 - page 9, line 18 page 6, lines 10-23 -----	1-18
A	BJOERN MATTHIAS ET AL: "Safety of collaborative industrial robots: Certification possibilities for a collaborative assembly robot concept", ASSEMBLY AND MANUFACTURING (ISAM), 2011 IEEE INTERNATIONAL SYMPOSIUM ON, IEEE, 25 May 2011 (2011-05-25), pages 1-6, XP031955901, DOI: 10.1109/ISAM.2011.5942307 ISBN: 978-1-61284-342-1 Sections I, III.B, III.C(5); Table V -----	1-18
A	BJOERN M. ET AL: "Injury Risk Quantification for Industrial Robots in Collaborative Operation with Humans", Robotics (ISR), 2010 41st International Symposium on and 2010 6th German Conference on Robotics (ROBOTIK), 7 June 2010 (2010-06-07), 9 June 2010 (2010-06-09), pages 171-176, XP002695928, ISBN: 978-3-8007-3273-9 Retrieved from the Internet: URL:http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5756793 [retrieved on 2013-04-19] Sections 1, 3.3 - 6 -----	1-18

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2013/054032

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2010063319 A1	10-06-2010	CN 102239032 A EP 2364243 A1 US 2011264266 A1 WO 2010063319 A1	09-11-2011 14-09-2011 27-10-2011 10-06-2010
US 2008161970 A1	03-07-2008	CN 101039779 A JP 3927994 B2 US 2008161970 A1 US 2009125145 A1 WO 2006043396 A1	19-09-2007 13-06-2007 03-07-2008 14-05-2009 27-04-2006
US 2010087955 A1	08-04-2010	CN 101646534 A CN 102229147 A CN 102229148 A CN 102248537 A JP 4243326 B2 US 2010087955 A1 WO 2009001550 A1	10-02-2010 02-11-2011 02-11-2011 23-11-2011 25-03-2009 08-04-2010 31-12-2008
US 2009105880 A1	23-04-2009	CN 101213052 A CN 101870108 A CN 101870112 A JP 4056080 B2 US 2009105880 A1 WO 2007080733 A1	02-07-2008 27-10-2010 27-10-2010 05-03-2008 23-04-2009 19-07-2007
US 2006049939 A1	09-03-2006	AT 354056 T DE 102004043514 A1 EP 1635107 A1 ES 2278361 T3 US 2006049939 A1	15-03-2007 09-03-2006 15-03-2006 01-08-2007 09-03-2006
WO 2012076029 A1	14-06-2012	NONE	