Risk assessment

Collaborative Robot Safety System

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# Introduction

@TODO

This document is based on ISO 12100, ISO 10218-1, ISO 10218-2, ISO 13849-1 and ISO TS 15066

Safety measures are taken using the procedure as displayed in Figure 1. This figure can be found in ISO 13849-1.

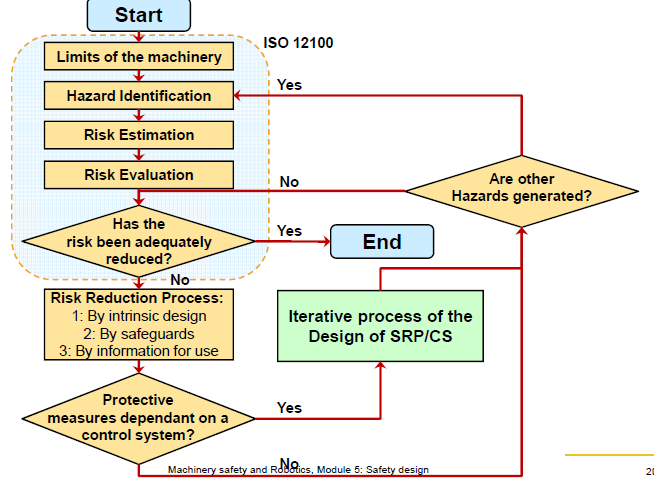


Figure 1 Procedure for taking safety measures

# Basic machine description

## Intended use

@TODO

The turtlebot drives from point A to point B, carrying one or multiple products.

If logical, it exchanges one or more of its products with other bots to optimize the path of the product to its destination. If it encounters an obstacle it will attempt to plan a different path, thereby avoiding it.

If this is not possible, the robot will resort to a safe state, or error loop.

When point B is reached, the products will be taken off and new ones might be put on again. This starts the process again.

## Machine components

@TODO

# Machine specifications

|  |  |
| --- | --- |
| **Machine Limits** | |
| Machine Name/Type | Turtlebot |
| Intended Environment | Industrial |
| Intended Use | Product transportation |
| Robot mass | 6.3 kg |
| Robot payload | Max 5 kg |
| Max speed | 0.7m/s in theory |
| Machine Dimensions | 354\*354\*420 mm |
| Machine Environment | Warehouse/factory, non-explosive, non-flammable |

|  |  |
| --- | --- |
| **Operational and Maintenance Information** | |
| **Operational Information** | |
| No. of Operators | 1 |
| **Maintenance Operation** | |
| Maintained by | Trained staff |
| Maintenance Frequency | When necessary |
| Cleaning | Operator |
| Jamming repair | Operator |

|  |  |
| --- | --- |
| **Power source** | |
| Main Feed, Elec. Supply: | Li-Ion Battery, standard = 2200 mAh or extended = 4400 mAh 19-5V |
| Pneumatic Supply | Not Applicable |
| Hydraulic Supply | Not Applicable |

# 

# Device specifications

|  |  |
| --- | --- |
| **Machine Limits** | |
| Machine Name/Type | Robot Integrated Transfer System R.I.T.S |
| Intended Environment | Industrial |
| Intended Use | Material handling |
| Device mass | 3 kg |
| Device payload | Max 2 kg |
| Max speed | To be defined |
| Machine Dimensions | To be defined |
| Machine Environment | Warehouse/factory, on top of turtlebotm non-explosive, non-flammable |

|  |  |
| --- | --- |
| **Operational and Maintenance Information** | |
| **Operational Information** | |
| No. of Operators | 1 |
| **Maintenance Operation** | |
| Maintained by | Trained staff |
| Maintenance Frequency | When necessary |
| Cleaning | Operator |
| Jamming repair | Operator |

|  |  |
| --- | --- |
| **Power source** | |
| Main Feed, Elec. Supply: | Li-Ion Battery, standard = 2200 mAh or extended = 4400 mAh 19-5V |
| Pneumatic Supply | Not Applicable |
| Hydraulic Supply | Not Applicable |

# Hazards

## Hazard identification

Hazards are determined by considering the following sources:

* Annex I of ISO 10218-1
* Annex I of ISO 10218-2
* ISO TS 15066
* Reasonable foreseeable misuse
* Common sense

## Risk classification method

The Evaluation methodology is based on *Pilz criteria* and experience, an evaluation of the factors, Degree of Possible Harm (DPH), Probability of Occurrence of a Hazardous Event (PO), Possibility of Avoidance (PA) and Frequency and/or duration of Exposure (FE), and has been performed on the risk related with each hazard. A Pilz Hazard Rating has then been calculated from the following formula:

PHR = DPH x PO x PA x FE (1)

Table 1 Grading severity

|  |  |
| --- | --- |
| **Degree of Possible Harm (DPH)** | |
| **Grade** | **Consequence** |
| 0.25 | Scratch/ bruise |
| 0.5 | Lacerations/ cut/ mild ill health effect/ minor burns |
| 3 | Fracture major bone – hand, arm, leg |
| 5 | Fracture major bone – fingers, toes |
| 8 | Loss of 2 or 2 fingers/ toes or major burns |
| 11 | Leg/hand amputation, partial loss of hearing or eye |
| 15 | Amputation of 2 legs/hands, total loss of hearing/sight in both ears/ eyes |
| 25 | Critical injuries or permanent illness/condition/injury |
| 40 | Single Fatality |
| 65 | Catastrophe |

Table 2 Grading possibility of occurrence of hazard event

|  |  |
| --- | --- |
| **Possibility of Occurrence of Hazard Event (PO)** | |
| **Grade** | **Possibility** |
| 0.05 | Almost impossible |
| 1.25 | Unlikely |
| 2.5 | Possible |
| 4 | Probable |
| 6 | Certain |

Table 3 Grading possibility of avoidance

|  |  |
| --- | --- |
| **Possibility of Avoidance (PA)** | |
| **Grade** | **Possibility** |
| 0.75 | Possible |
| 2.5 | Possible under certain circumstances |
| 5 | Not possible |

Table 4 Grading frequency of exposure

|  |  |
| --- | --- |
| **Frequency of Exposure (FE)** | |
| **Grade** | **Frequency** |
| 0.05 | Annually |
| 1 | Monthly |
| 2 | Weekly |
| 3 | Daily |
| 4 | Hourly |
| 5 | Constantly |

Finally, the risk is classified according to Table 5. This classification table is a scaled version of the original Fine & Kinney version, in order to match the grading system that is being used in this risk assessment.

Table 5 Risk classification table

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Risk classification table** | | | | |
| **PHR** | | **Risk** | | **Comment** |
|  | 1-10 | Negligible Risk | Presents practically no risk to health and safety, no further risk reduction measures are required. | |
|  | 11-20 | Very Low Risk | Presents very little risk to health and safety, no significant risk reduction measures are required, may necessitate the use of personal protective equipment and/or training. | |
|  | 21-45 | Low Risk | Risk to health and safety is present, but low. Risk reduction measures must be considered. | |
|  | 46-160 | Significant Risk | The risk associated with the hazard is substantial enough to require risk reduction measures. These measures should be implemented at the next suitable opportunity. | |
|  | 161-500 | High Risk | Potentially dangerous hazard, which requires risk reduction measures to be implemented urgently. | |
|  | 501+ | Very high Risk | Risk reduction measures should be implemented immediately, corporate management should be notified. | |

## Risk analysis

All hazards and classifications can be found in Table 6.

Table 6 Hazards with corresponding risks

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Hazards** | **DPH** | **PO** | **PA** | **FE** | **PHR** | **Risk classification** |
| **Mechanical:** |  |  |  |  |  |  |
| Turtlebot drives into a person | 0.01 | 2 | 1 | 3 | 0.06 |  |
| Person walks into a Turtlebot | 0.25 | 3 | 0.5 | 4 | 0.75 |  |
| Person trips over a Turtlebot and hits head/neck hard | 40 | 0.05 | 3 | 0.5 | 3 |  |
| Person trips over a Turtlebot and falls with his back on top of it | 25 | 0.3 | 2 | 1 | 15 |  |
| A person’s hair could get entangled with the Turtlebot’s wheels | 0.25 | 0.05 | 4 | 0.5 | 0.025 |  |
| Product falls from +- 30cm height on body part | 3 | 0.1 | 2 | 1 | 0.6 |  |
| Forklift runs into turtlebot | 8 | 2.5 | 2.5 | 1 | 50 |  |
| A person’s body part gets stuck in the clamp | 3 | 1.25 | 1 | 0.5 | 1.875 |  |
| A carriage falls off and a person Trips over it | 5 | 1.5 | 2 | 1 | 15 |  |
| A sharp part of the robot could cut a person | 0.5 | 2.5 | 2.5 | 2 | 6.25 |  |
| A carriage breaks loose and flies into a person | 0.25 | 0.05 | 5 | 1 | 0.0625 |  |
| A part of the robot breaks off and flies into a person | 0.5 | 1.25 | 2.5 | 1 | 1.5625 |  |
| During repairs the robot turns on | 0.25 | 1.25 | 2.5 | 1 | 0.78125 |  |
| During cleaning the robot turns on | 0.25 | 1.25 | 2.5 | 2 | 1.5625 |  |
| Robot is used as step and person falls | 5 | 2.5 | 2.5 | 1.5 | 46.875 |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| **Electrical hazard:** |  |  |  |  |  |  |
| Power supply failure due to short circuit |  |  |  |  |  |  |
| Battery overload |  |  |  |  |  |  |
| Charging of deeply discharged batteries |  |  |  |  |  |  |
| Contact with live battery terminals |  |  |  |  |  |  |
| Battery short-circuit |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| Power supply failure due to voltage overload |  |  |  |  |  |  |
| Turtlebot catches fire because a wrong loader was used |  |  |  |  |  |  |
| Cables disconnect from the robot |  |  |  |  |  |  |
| **Noise hazard:** |  |  |  |  |  |  |
| Noise produced by the alarm the robot could give in warning |  |  |  |  |  |  |

Hazards are not specific for the ABB IRB140, they can apply for other brands and types of robotic arms.

As stated in section 4.1: in the selection of the hazards, the additional hazards from application-specific components, such as end-effector, payload, fixtures, working environment, etc. are not considered. All remaining hazards are elaborated below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Hazard Identification | | | Hazard No. | 1.1 |
| Title | Touch a worker |  | | |
| Location | Shared workspace |
| Target | Human eye |
| Activity | Normal operation in shared workspace |
| Hazard Type | Mechanical | | | |
| Consequence | Impact | | | |
| Description | The robot could accidently touch a worker | | | |
| References: | ISO 10218-1 | | | |
| Risk Estimation and Evaluation | | | | |
| Severity | 100 | Exposure time | | 10 |
| Probability | 1 | Risk (S x E x P) | | 1000 |
| Important risk | | | | |
| Risk Reduction | | | Reference | |
| Cover payload | | |  | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 1.5 | Exposure time | | 10 |
| Probability | 6 | Risk (S x E x P) | | 90 |
| Acceptable risk | | | | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
| Hazard Identification | | | Hazard No. | 1.2 |
| Title | Run into worker |  | | |
| Location | Shared workspace |
| Target | Head (temple) |
| Activity | Normal operation in shared workspace |
| Hazard Type | Mechanical | | | |
| Consequence | Impact | | | |
| Description | The robot could accidently run into a worker | | | |
| References: | ISO 10218-1 | | | |
| Risk Estimation and Evaluation | | | | |
| Severity | 200 | Exposure time | | 10 |
| Probability | 10 | Risk (S x E x P) | | 20000 |
| Very high risk | | | | |
| Risk Reduction | | | Reference | |
| Add a padding on the robot to reduce impact | | | ISO TS 15066 [5.5.5.4 b1] | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 37.5 | Exposure time | | 10 |
| Probability | 10 | Risk (S x E x P) | | 3750 |
| High risk | | | | |
| Risk Reduction | | | Reference | |
| Adapting speed depending on distance to human | | | ISO 10218-1 [5.6.2] | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 6.25 | Exposure time | | 10 |
| Probability | 3 | Risk (S x E x P) | | 187.5 |
| Possible risk | | | | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
| Hazard Identification | | | Hazard No. | 1.3 |
| Title | Limbs get stuck |  | | |
| Location | Robot mechanical structure with holes |
| Target | Limbs, arm |
| Activity | Normal operation in shared workspace |
| Hazard Type | Mechanical | | | |
| Consequence | crushing | | | |
| Description | Workers limbs could get stuck in the robot | | | |
| References: | ISO 10218-1 | | | |
| Risk Estimation and Evaluation | | | | |
| Severity | 37.5 | Exposure time | | 10 |
| Probability | 6 | Risk (S x E x P) | | 2250 |
| High risk | | | | |
| Risk Reduction | | | Reference | |
| Cover the robot so body parts can't get stuck in the robot. | | | ISO TS 15066 [5.5.5.4 a3] | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 37.5 | Exposure time | | 10 |
| Probability | 0.2 | Risk (S x E x P) | | 75 |
| Acceptable risk | | | | |
|  |  |  |  |  |
| Hazard Identification | | | Hazard No. | 1.4 |
| Title | Human crushed |  | | |
| Location | On a heavy obstacle (e.g. wall or workpiece) |
| Target | Head (temple) |
| Activity | Normal operation in shared workspace |
| Hazard Type | Mechanical | | | |
| Consequence | crushing | | | |
| Description | Worker could get crushed between the robot and the workbench or workpiece | | | |
| References: | ISO 10218-1 | | | |
| Risk Estimation and Evaluation | | | | |
| Severity | 200 | Exposure time | | 10 |
| Probability | 3 | Risk (S x E x P) | | 6000 |
| Very high risk | | | | |
| Risk Reduction | | | Reference | |
| Adapting speed depending on distance to human | | | ISO 10218-1 [5.6.2] | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 200 | Exposure time | | 10 |
| Probability | 1 | Risk (S x E x P) | | 2000 |
| High risk | | | | |
| Risk Reduction | | | Reference | |
| Measure the force feedback | | |  | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 37.5 | Exposure time | | 10 |
| Probability | 1 | Risk (S x E x P) | | 375 |
| Possible risk | | | | |
|  |  |  |  |  |
| Hazard Identification | | | Hazard No. | 1.5 |
| Title | Human pinned |  | | |
| Location | On a heavy obstacle (e.g. wall or workpiece) |
| Target | Head (temple) |
| Activity | Normal operation in shared workspace |
| Hazard Type | Mechanical | | | |
| Consequence | Trapping | | | |
| Description | Worker could get pinned down between the robot and walls or other objects | | | |
| References: | ISO 10218-1 | | | |
| Risk Estimation and Evaluation | | | | |
| Severity | 1.5 | Exposure time | | 10 |
| Probability | 1 | Risk (S x E x P) | | 15 |
| Acceptable risk | | | | |
|  |  |  |  |  |
| Hazard Identification | | | Hazard No. | 1.6 |
| Title | Human hair entangled |  | | |
| Location | Shared workspace |
| Target | Human hair |
| Activity | Normal operation in shared workspace |
| Hazard Type | Mechanical | | | |
| Consequence | Entanglement, Drawing-in | | | |
| Description | A worker’s hair could get entangled in the robot arm | | | |
| References: | ISO 10218-1 | | | |
| Risk Estimation and Evaluation | | | | |
| Severity | 22 | Exposure time | | 10 |
| Probability | 6 | Risk (S x E x P) | | 1320 |
| Important risk | | | | |
| Risk Reduction | | | Reference | |
| Cover the robot so body parts can't get stuck in the robot. | | | ISO TS 15066 [5.5.5.4 a3] | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 22 | Exposure time | | 10 |
| Probability | 1 | Risk (S x E x P) | | 220 |
| Possible risk | | | | |
| Risk Reduction | | | Reference | |
| Adapting speed depending on distance to human | | | ISO 10218-1 [5.6.2] | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 6.25 | Exposure time | | 10 |
| Probability | 1 | Risk (S x E x P) | | 62.5 |
| Acceptable risk | | | | |
|  |  |  |  |  |
| Hazard Identification | | | Hazard No. | 1.7 |
| Title | Clothes entangled |  | | |
| Location | Robot joints |
| Target | Clothes (sleeve, hood) |
| Activity | Normal operation in shared workspace |
| Hazard Type | Mechanical | | | |
| Consequence | Entanglement, Drawing-in | | | |
| Description | A worker’s loose clothing could get entangled in the robot arm | | | |
| References: | ISO 10218-1 | | | |
| Risk Estimation and Evaluation | | | | |
| Severity | 22 | Exposure time | | 10 |
| Probability | 3 | Risk (S x E x P) | | 660 |
| Important risk | | | | |
| Risk Reduction | | | Reference | |
| Cover the robot so clothing can't get stuck in the robot. | | | ISO TS 15066 [5.5.5.4 a3] | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 22 | Exposure time | | 10 |
| Probability | 1 | Risk (S x E x P) | | 220 |
| Possible Risk | | | | |
| Risk Reduction | | | Reference | |
| Adapting speed depending on distance to human | | | ISO 10218-1 [5.6.2] | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 6.25 | Exposure time | | 10 |
| Probability | 1 | Risk (S x E x P) | | 62.5 |
| Acceptable risk | | | | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
| Hazard Identification | | | Hazard No. | 1.8 |
| Title | Jewelry entangled |  | | |
| Location | Robot joints |
| Target | Jewelry(fingers, neck and arms) |
| Activity | Normal operation in shared workspace |
| Hazard Type | Mechanical | | | |
| Consequence | Entanglement, Drawing-in | | | |
| Description | A worker’s jewellery could get entangled in the robot arm | | | |
| References: | ISO 10218-1 | | | |
| Risk Estimation and Evaluation | | | | |
| Severity | 37.5 | Exposure time | | 10 |
| Probability | 1 | Risk (S x E x P) | | 375 |
| Possible risk | | | | |
| Risk Reduction | | | Reference | |
| Adapting speed depending on distance to human | | | ISO 10218-1 [5.6.2] | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 6.25 | Exposure time | | 10 |
| Probability | 1 | Risk (S x E x P) | | 62.5 |
| Acceptable risk | | | | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Hazard Identification | | | Hazard No. | 1.9 |
| Title | Push workpiece |  | | |
| Location | Shared workspace and surrounding area |
| Target | Lower body |
| Activity | Normal operation in shared workspace |
| Hazard Type | Mechanical | | | |
| Consequence | crushing | | | |
| Description | The robot could push a heavy workpiece, which makes it fall on workers around the workspace of the robot. | | | |
| References: | ISO 10218-1 | | | |
| Risk Estimation and Evaluation | | | | |
| Severity | 100 | Exposure time | | 10 |
| Probability | 6 | Risk (S x E x P) | | 6000 |
| Very high risk | | | | |
| Risk Reduction | | | Reference | |
| Adapting speed depending on distance to workpiece | | | ISO 10218-1 [5.6.2] | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 100 | Exposure time | | 10 |
| Probability | 0.5 | Risk (S x E x P) | | 500 |
| Important risk | | | | |
| Risk Reduction | | | Reference | |
| Use force feedback | | |  | |
|
|
| Risk Estimation and Evaluation | | | | |
| Severity | 100 | Exposure time | | 10 |
| Probability | 0.1 | Risk (S x E x P) | | 10 |
| Acceptable risk | | | | |