Risk assessment

Collaborative Robot Safety System

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# Introduction

This document describes the safety assessment for the multi-robot transport project.

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.

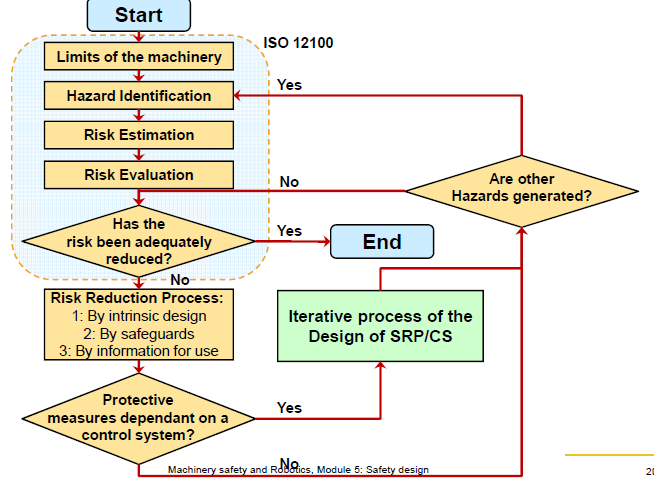


Figure 1 Procedure for taking safety measures

# Basic machine description

## Intended use

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.

The robots are not meant to be used in another fashion than specified above.

## Machine components

Not yet defined

# 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, no forklift |

|  |  |
| --- | --- |
| **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 turtlebot 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. | |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **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 | 8 | 0.5 | 2.5 | 0.5 | 5 |  |
| Battery overload | 8 | 0.05 | 2.5 | 3 | 3 |  |
| Charging of deeply discharged batteries | 8 | 0.05 | 2.5 | 3 | 3 |  |
| Contact with live battery terminals | 8 | 0.05 | 2.5 | 1.5 | 1.5 |  |
| Battery short-circuit | 8 | 0.05 | 2.5 | 3 | 3 |  |
|  |  |  |  |  |  |  |
| Power supply failure due to voltage overload | 8 | 0.5 | 2.5 | 0.5 | 5 |  |
| Cables disconnect from the robot | 0.5 | 1 | 0.1 | 3 | 0.15 |  |
| **Noise hazard:** |  |  |  |  |  |  |
| Noise produced by the alarm the robot could give in warning | 0.5 | 6 | 5 | 4 | 60 |  |

## Risk analysis

All hazards and classifications can be found in Table 6.

Table 6 Hazards with corresponding risks

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Hazard Identification | | | Hazard No. | 1.1 |
| Title | Person trips over a Turtlebot and falls with his back on top of it | C:\Users\radel\AppData\Local\Microsoft\Windows\INetCache\Content.Word\IMAG0004.jpg | | |
| Location | Warehouse or factory |
| Target | Human |
| Activity | Normal operation |
| Task | Moving between target locations possibly carrying products |
| Sub Task | Moving |
| Hazard Type | Mechanical Hazard with the consequence of being paralyzed, or have permanent back problems. | | | |
| Sub Type | Person falls with back on top op turtlebot | | | |
| Description | A person trips over a turtlebot, causing the person to fall on top of the turtlebot with his back. This could cause the person to be paralyzed or have permanent back issues. | | | |
| References: | ISO/TS 15066, ISO 10218 | | | |
| Risk Estimation and Evaluation | | | | |
| Degree of Possible Harm: | 8 | Possibility of Avoidance: | | 2.5 |
| Probability of Occurance of a Hazardous Event: | 2.5 | Frequency And/or Duration of Exposure: | | 1 |
| Pilz Hazard Rating (PHR): | 50 | Summary Level: | Significant Risk | |
| Risk Reduction | | | Reference | |
| The Turtlebot will make sounds indicating its location | | |  | |
| Risk Estimation and Evaluation | | | | |
| Degree of Possible Harm: | 8 | Possibility of Avoidance: | | 2 |
| Probability of Occurance of a Hazardous Event: | 1 | Frequency And/or Duration of Exposure: | | 1 |
| Pilz Hazard Rating (PHR): | 16 | Summary Level: | Very Low Risk | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Hazard Identification | | | Hazard No. | 1.2 |
| Title | Forklift runs into turtlebot | C:\Users\radel\AppData\Local\Microsoft\Windows\INetCache\Content.Word\IMAG0011.jpg | | |
| Location | Warehouse or factory |
| Target | Human |
| Activity | Normal operation |
| Task | Moving between target locations possibly carrying products |
| Sub Task | Moving |
| Hazard Type | Fire Hazard | | | |
| Sub Type | Major burns | | | |
| Description | A person drives into a turtlebot with a forklift and causes so much damage the battery gets punctured and catches fire | | | |
| References: | ISO/TS 15066, ISO 10218 | | | |
| Risk Estimation and Evaluation | | | | |
| Degree of Possible Harm: | 25 | Possibility of Avoidance: | | 2 |
| Probability of Occurance of a Hazardous Event: | 0.3 | Frequency And/or Duration of Exposure: | | 1 |
| Pilz Hazard Rating (PHR): | 15 | Summary Level: | Very Low Risk | |
| Risk Reduction | | | Reference | |
| The Turtlebot will make sounds indicating its location | | |  | |
| Risk Estimation and Evaluation | | | | |
| Degree of Possible Harm: | 25 | Possibility of Avoidance: | | 2 |
| Probability of Occurance of a Hazardous Event: | 0.05 | Frequency And/or Duration of Exposure: | | 1 |
| Pilz Hazard Rating (PHR): | 2.5 | Summary Level: | Negligible risk | |
| Risk Reduction | | | Reference | |
| No forklifts allowed in the warehouse | | |  | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Risk Estimation and Evaluation | | | | |
| Degree of Possible Harm: | 8 | Possibility of Avoidance: | | 2 |
| Probability of Occurance of a Hazardous Event: | 1 | Frequency And/or Duration of Exposure: | | 0.5 |
|  |  |  | |  |
|  |  |  | |  |
| Pilz Hazard Rating (PHR): | 8 | Summary Level: | Negligible Risk | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Hazard Identification | | | Hazard No. | 1.1 |
| Title | A carriage falls off and a person Trips over it | C:\Users\radel\AppData\Local\Microsoft\Windows\INetCache\Content.Word\IMAG0007.jpg | | |
| Location | Warehouse or factory |
| Target | Human |
| Activity | Normal operation |
| Task | Moving between target locations carrying products |
| Sub Task | Moving |
| Hazard Type | Mechanical Hazard with the consequence of falling | | | |
| Sub Type | Fracture major bone (arm, hand or leg) | | | |
| Description | A person trips over a product the turtlebot has dropped due to a failure. The person falls and fractures a major bone. | | | |
| References: | ISO/TS 15066, ISO 10218 | | | |
| Risk Estimation and Evaluation | | | | |
| Degree of Possible Harm: | 5 | Possibility of Avoidance: | | 2 |
| Probability of Occurance of a Hazardous Event: | 1.5 | Frequency And/or Duration of Exposure: | | 1 |
| Pilz Hazard Rating (PHR): | 15 | Summary Level: | Very Low Risk | |
| Risk Reduction | | | Reference | |
| The carriages are painted in bright colors | | |  | |
| Risk Estimation and Evaluation | | | | |
| Degree of Possible Harm: | 8 | Possibility of Avoidance: | | 0.75 |
| Probability of Occurance of a Hazardous Event: | 1 | Frequency And/or Duration of Exposure: | | 1 |
| Pilz Hazard Rating (PHR): | 16 | Summary Level: | Very Low Risk | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | |  |  |
| Hazard Identification | | | Hazard No. | 1.1 |
| Title | Robot is used as step and person falls | C:\Users\radel\AppData\Local\Microsoft\Windows\INetCache\Content.Word\IMAG0009.jpg | | |
| Location | Warehouse or factory |
| Target | Human |
| Activity | Normal operation |
| Task | Moving between target locations carrying products |
| Sub Task | Stationary |
| Hazard Type | Mechanical Hazard with the consequence of falling | | | |
| Sub Type | Fracture major bone (arm, hand or leg) | | | |
| Description | A person falls of a turtlebot while using it as a step. | | | |
| References: | ISO/TS 15066, ISO 10218 | | | |
| Risk Estimation and Evaluation | | | | |
| Degree of Possible Harm: | 5 | Possibility of Avoidance: | | 2 |
| Probability of Occurance of a Hazardous Event: | 2.5 | Frequency And/or Duration of Exposure: | | 1 |
| Pilz Hazard Rating (PHR): | 15 | Summary Level: | Very Low Risk | |
| Risk Reduction | | | Reference | |
| Waarschuwingsstickers | | |  | |
| Risk Estimation and Evaluation | | | | |
| Degree of Possible Harm: | 5 | Possibility of Avoidance: | | 2 |
| Probability of Occurance of a Hazardous Event: | 2.5 | Frequency And/or Duration of Exposure: | | 0.5 |
| Pilz Hazard Rating (PHR): | 7.5 | Summary Level: | Negligible Risk | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | |  |  |
| Hazard Identification | | | Hazard No. | 1.1 |
| Title | Robot is used as step and person falls | C:\Users\radel\AppData\Local\Microsoft\Windows\INetCache\Content.Word\IMAG0021.jpg | | |
| Location | Warehouse or factory |
| Target | Human |
| Activity | Normal operation |
| Task | Moving between target locations carrying products |
| Sub Task | Moving |
| Hazard Type | Noise Hazard | | | |
| Sub Type | Hearing Damage | | | |
| Description | The Turtlebot’s warning signals are too loud | | | |
| References: | ISO/TS 15066, ISO 10218 | | | |
| Risk Estimation and Evaluation | | | | |
| Degree of Possible Harm: | 0.5 | Possibility of Avoidance: | | 5 |
| Probability of Occurance of a Hazardous Event: | 6 | Frequency And/or Duration of Exposure: | | 4 |
| Pilz Hazard Rating (PHR): | 60 | Summary Level: | Significant Risk | |
| Risk Reduction | | | Reference | |
| Lower volume | | |  | |
| Risk Estimation and Evaluation | | | | |
| Degree of Possible Harm: | 0.25 | Possibility of Avoidance: | | 5 |
| Probability of Occurance of a Hazardous Event: | 6 | Frequency And/or Duration of Exposure: | | 1 |
| Pilz Hazard Rating (PHR): | 7.5 | Summary Level: | Negilible Risk | |