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Safety evaluation of robot applications Subject: Humanoid robots

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Contents

1 Introduction

This methodology is used to evaluate the safety of an application involving collaboration between a human and a robot. Safety is a necessary condition, but safety can be achieved with various performance levels of the overall system and different protection methods. The methodology consists of several steps, and it should be followed in the order given here. The introductory part first defines the necessary terms, then provides an overview of the methodology for easier orientation in the chapter 2, pg. 4. The core of the methodology is the chapter 3, pg. 5, which goes through the whole process in detail.

1.1 Definition of the methodology

The methodology deals with the deployment of robots in a mode where human presence in the robot's workspace is assumed. The methodology evaluates the possibilities of safe deployment of robots concerning the needs and goals of the client. Special emphasis is then placed on the so-called collaborative robots, a.k.a. cobots.

The following assumptions must apply in order for the methodology to be meaningfully implemented:

- ☐ Robot deployment is considered.
- ☐ The presence of a human in the robot's workspace during its normal operation is considered.

The methodology does not address situations where the robot's workspace is accessed on special occasions (e.g., downtime, maintenance, programming, collision recovery).

1.2 Policy for safe work with robots

For completeness, we present the minimum safety principles for the work with robots. The methodology assumes their use:

- Only a properly trained person works with the robot.
- When working with the robot, there is always at least one additional person present to stop the robot if necessary and call for help.
- The robot clearly indicates its operation status (in operation, it is switched off, etc.).
- When working with the robot, it is necessary to pay attention to the whole body of the robot and not only to the end effector.
- Unknown or unapproved robot movements should be performed only under safe conditions to prevent a possible sudden collision.

2 Overview of the methodology

Safety verification consists of the following main phases:

- Summarize the application specification
- Safety evaluation
- Risk reduction

Each phase is accompanied by a checklist of tasks that must be completed before moving on to the next phase or ending the deployment. The integrator should go through the checklist step by step and evaluate each request. If a particular step does not comply, it must be corrected before continuing or terminating the deployment because the given condition is unsatisfactory.

The methodology is also accompanied by examples (text) or counterexamples (⚠ text) where the methodology leads to the rejection of the use of a collaborative robot.

The result of the methodology may be the conclusion that the robot cannot be deployed or several options for deploying the robot safely.

3 Methodology

3.1 Application analysis

☐ What is the intended tool or gripper and what are its properties?

☐ What is the required cycle rate and speed of the robot? What are the limits for the application (min, max)?

☐ Are all the robot speeds that will be used in the application known?

☐ Is the spatial layout for the proposed task known?

☐ What are the expected human interactions?

☐ Are there possible human contact situations?

The client presents a task where they would like to automate palletizing. Workers modify the parts on the production line. The pallet with parts was originally picked up by a worker at the end of the line and placed into a larger crate. A robot should be deployed instead of this worker. Due to the limited space, a collaborative robot is preferred, as the necessary fencing of the space would block part of the shop floor. On average, a new pallet arrives at the end of the line every 5 seconds. The path that the robot would have to travel (i.e. from the line to the crate) is 0.3 m. The weight of the pallet is 8 kg.

⚠ The client requires a production cycle rate higher than what the cobots allow. For example, ten times a second would be unattainable with the given distance.

3.2 Evaluating task safety

Based on the task assignment and possible deployment locations, it is necessary to verify whether the application is safe to run with the robot.

Initial questions for verification of feasibility:

☐ Is the tool itself dangerous (e.g., sharp or hot)?

☐ Are excessive forces needed during the application?

⚠ The client expects an application with a dangerous tool, e.g., welding on an object that is to be manipulated by the human.

Use the Risk Matrix, see Tab. 1. The matrix combines the frequency of an event with its severity to determine the overall risk. Event probabilities are:

- **F**requent - occurs every cycle,
- **P**robable - occurs some cycles, e.g., weekly during maintenance,
- **O**ccasional - the event is expected to occur at most a month,
- **R**are - the event is expected to occur at most once a year, e.g., during a planned outage,
- **N**ever - the event is not expected to occur.

The severity of the risk is:

- **H**igh - can cause serious injury or death,
- **M**ild - can cause moderate injuries, e.g. cuts, uncomplicated fractures,
- **L**ow - can lead at most to bruising or short-term incapacity for work,
- **N**egligible - does not cause any injuries or only minor abrasions.

Following from these, the resulting overall risk is:

- **H**igh - the application cannot be used and needs to be redesigned,
- **M**oderate - the risk needs to be reduced, or at least the application users require training in its safe use and only trained specialized personnel should have access to the application,
- **L**ow - the risk needs to be reduced, or at least basic safety training needs to be performed. This can be part of the usual Occupational safety and health training,
- **N**egligible - no further adjustments are needed.

Risk Matrix

		Severity			
Occurence		H	M	L	N
	F	H	H	M	L
	P	H	H	M	L
	O	H	M	L	N
	R	M	L	N	N
	N	L	N	N	N

Table 1: The intersection of probability and severity leads to the evaluation of the risk of the given application. Occurence probabilities can be: **F**requent, **P**robable, **O**cassional, **R**are, **N**ever. The severity of the risk can be: **H**igh, **M**ild, **L**ow, or **N**egligible. The resulting overall risk may be: **H**igh, **M**ild, **L**ow, or **N**egligible.

When evaluating palletizing, it is considered that at each cycle (i.e., frequent event, **F**, first line) the employee will be forced to ensure that the pallet is suitably positioned for the gripping robot. At the same time, the worker will hold the pallet and can also hold it in places where the robot picks up the pallet. A collaborative gripper grips the pallet, and therefore, no severe injury will occur, but it can be painful because the gripper has to grab the pallet to lift it. The severity will be evaluated as negligible (**N**, fourth column). The overall risk will be assessed as light based on the risk matrix. To approve the application, the workers will need to be trained or the risk reduced somehow. Examples of risk reduction are: changing the robot's gripping position so that it could not catch the worker's hand or straighten the pallets and direct them to the robot by rails, thereby eliminating the need for human interaction.

If necessary, it is also possible to use the score created by Pilz, the so-called PHR (Pilz Hazard Rating), for more detailed analysis:

$$PHR = DPH \cdot PO \cdot PA \cdot FE \tag{1}$$

Where the values are derived from Tab. 3, and the result is compared with the Pilz score values from Tab. 2. We are currently evaluating the PHR for the planned application, and therefore any application with a significant risk cannot be approved. If an already deployed application is evaluated, it is possible to distinguish the severity in more detail.

PSR		Risk	Description
	1-10	Negligible	The application poses virtually no risk and can be deployed without further action.
	11-20	Low	The application does not present a risk that should be reduced, it is advisable to use personal protective equipment and conduct training .
	21-45	Moderate	Risk is present and risk mitigation measures must be considered.
	46 <	Significant	Risk requires the use of risk mitigation, otherwise the application cannot be approved.

Table 2: Values and evaluation of Pilz risk score.

Degree of Possible Harm (DPH)		Probability of Occurence (PO)	
Scratches, abrasions	0.25	Once a year	0.5
Lacerate or cut, small burns	0.5	Monthly	1
Small bone fracture (fingers)	3	Weekly	2
Large bone fracture (arms, legs, etc.)	5	Daily	3
Loss of a few fingers, more burns	8	Once an hour	4
Limb amputation, partial loss of sight, hearing	11	Every time	5
Amputation of two limbs, complete loss of sight, hearing	15		
Critical damage with lasting consequences	25		
Death of an individual	40		
Catastrophic	65		
Possibility of Avoidance (PA)		**Frequency of Exposure (FE)**	
Possible	0.75	Almost Never	0.05
Possible under certain circumstances	2.5	Unlikely	1.25
Impossible	5	Probable	2.5
		Common	4
		Certain	6

Table 3: Pilz risk score components.

When evaluating palletizing, it is considered that at each cycle, the employee will be forced to ensure that the pallet is properly positioned for the gripping robot (i.e., the frequency of exposure will be “every time”, value 5). At the same time, the worker will hold the pallet and can hold it even in places where the robot holds the pallet (i.e., the frequency of the risk itself is “probable”, value 2.5, with the possibility to avoid if the robot speed is reduced, value 0.75). A collaborative gripper grips this, and therefore no serious injury will occur. However, it can be painful because the gripper must grab the pallet hard enough to lift it (i.e., the possible injury rate is 0.25). The overall Pilz score of the task will be evaluated as $PHR = 5 \cdot 2.5 \cdot 0.75 \cdot 0.25 = 2.34$. The table of PHR ranges shows that the risk is negligible.

3.3 Risk reduction

Based on the task analysis, the risks of the application should be clear. These risks need to be reduced or assessed as negligible. In conclusion, the following should be answered:

- ☐ Was the risk assessment performed and suitable risk reduction suggested and implemented?

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- ☐ Has the final risk analysis, following the risk reduction, led to the risk being negligible?

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Appendices

Risk and change analysis record - example

Risk Analysis Record			
Document number:	RIZ20211109-SEA	**Number of operators:**	2
Application Name:	Palletizing Components	**Untrained Access:**	No
Application description:	Robot takes goods from the basket and palletizes them on prepared pallets.	**Hours of operation per day:**	12
Application purpose:	Palletization	**Application location:**	Company X, operation Y
Model:	UR10e	**Risk analysis performed by:**	Jan Novák
Machine modification:	Gripper qb SoftHand Industry	**Risk analysis date:**	2021/10/10

Change Log			
ID	**Date**	**Description of change**	**Signature**
1	2020/10/10	Introductory risk analysis	Jan Novák

Risk analysis record - Example

			Risk evaluation				Evaluation after mitigation		
ID	Risk	Threat	Severity	Probability.	Ratings	Measures	Severity	Probability.	Rating
001	Sharp Edges of EE	Worker hurt by EE	M	P	H	Safety training, outer edges covered with a protective layer	N	P	L
002	Pallet Drop	Workers Near Robot, Especially Lower Limbs	M	N	N	-	-	-	-
003	Compression by Pallets	Worker holding pallet	M	O	M	Safety training, pallet laying speed has been reduced	L	O	L

The example shows three assessed risks. Each identified risk is assigned a unique ID, the originator of the risk is described. Subsequently, the risk is evaluated according to Tab. 1. If the overall risk assessment is higher than **L**ight, the risk needs to be reduced. See the example above. For the sake of brevity, the measures can only be indicated by an abbreviation. In that case, the report should be accompanied by a list of the applied measures used and their abbreviations.

Risk and change analysis record

Risk Analysis Record			
Document number:		**Number of operators:**	
Application Name:		**Untrained Access:**	
Application description:		**Hours of operation per day:**	
Application Purpose:		**Application Location:**	
Model:		**Risk analysis performed by:**	
Machine modification:		**Risk analysis date:**	

Change Log			
ID	**Date**	**Description of change**	**Signature**

			Risk evaluation				Evaluation after mitigation		
ID	Risk	Threat	Severity	Probability	Rating	Measures	Severity	Probability	Rating