SaSeRoS

ROBOT DOCUMENTATION

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1. Introduction

The following instruction explains how to operate a cleaning robot. This robot is a useful invention and is called “CleanRob”. He works on the principle of a vacuum cleaner. This invention will be a great helper on a shopping mall. It will help you to keep the shopping mall clean thanks to safe and efficient control and performance of this robot. Besides the cleaning function there are some requirements that the robot should meet. “CleanRob” is able to detect objects and humans. In addition, he passes by without touching / or soft touches these and doing any harm to them. Thanks to the implemented safety features you can rely on his ability to detect stairs and to pass by without falling downstairs.

2. Specification

2.1 Environment

In this section you will learn more about the environment in which “CleanRob” can be used. The robot is allowed for usage in a crowded place like a shopping mall.

- Indoor use only
- Minimum room temperature: 10°C
- Maximum room temperature: 50℃
- Minimum obstacle height: 5 cm
- is able to detect large-sized objects with hard surfaces
- objects made from soft fabrics, from curved objects (e.g. a ball), or very thin and small objects are difficult to detect
- No heavily dusted areas
- No areas with fluid influence
- Only use at atmosphere air pressure
- Do not contact with fire
- Do not drive on slippery ground
- Is not able to detect ultrasonic absorbing material, may touch the obstacle
- Only for use on flat surfaces
- Do not use on dark surfaces

2.2 Users

Because of the implemented safety features this robot doesn’t pose a real threat to the humans. Nevertheless, it’s recommended to read the manual first before using the robot for the first time. Keep in mind that there is always a risk left and therefore no 100% of safety can be guaranteed.

To start the robot you have first to turn the key, the slot for the key you will find on the robot itself. *(→ application on future robot)*

Persons who are allowed to use the robot:

- only instructed persons who know about the risks which might arise using this robot

As far as no instructed person is available the usage of the robot is strictly forbidden!

2.3 Robot

2.3.1 Technical

- Weight: 100 kg
- Dimensions
  - Height: 100 cm
  - Diameter: 60 cm
- 3 motors (2 motors for driving and 1 for the Ultrasonic sensor)
- 5 Sensors *(the sound sensor will be implemented on the future robot)*
- IP Code 44
- Battery life without charging: 10 hours
- Emergency button under glass *(future implementation)*
- A slot for the key to start the robot
- Display for status messages
- Speakers to produce the warning sound
- Dust capacity: 10 liter
- Movement speed: 0.2m/s
- Cleaning capacity: up to 430m²/h
- 800 Watt vacuum motor
- Maximum use time: 20 years

Available sensors:

- **sound sensor *(will be added in future robot)***

- measures sound intensity
- detects the decibel level: softness or loudness of a sound
- is able to measure sound pressure levels up to 90 dB

➔ Additional fee!

- **ultrasonic range sensor**

- measures distances from 0 to 2.5 meters with a precision of +/- 3cm to objects using sound pulses

- the best readings are provided by large-sized objects with hard surfaces
- objects made from soft fabrics, from curved objects (e.g. a ball), or very thin and small objects can be difficult for the sensor to read

- **light sensor**
- allows detection of bright and dark light
- reads the light intensity in a room
- measures the light intensity on colored surfaces

- **two touch sensors (on the front and on the rear bumper)**
- measures two values: touch and no touch

2.3.2 Function

2.3.2.1 Normal operation

In the normal operation mode the robot does his regular cleaning procedure. In this mode the surrounding should not be exposed to a risk of collision.

To start the robot the operator has to turn the key in the key slot. Then the robot starts driving. While driving he scans the area in front of him. When an object is spotted he stops and begins to beep. Meanwhile he looks for free random direction. Finding it he turns to free direction and drives forward.

2.3.2.2 Collision with an object

If the robot can't detect an object and it comes to a collision with it, the robot drives backwards and then stops driving. Then he begins to beep. Meanwhile he looks for a free random direction. When he finds it he turns to the free direction and drives forward.

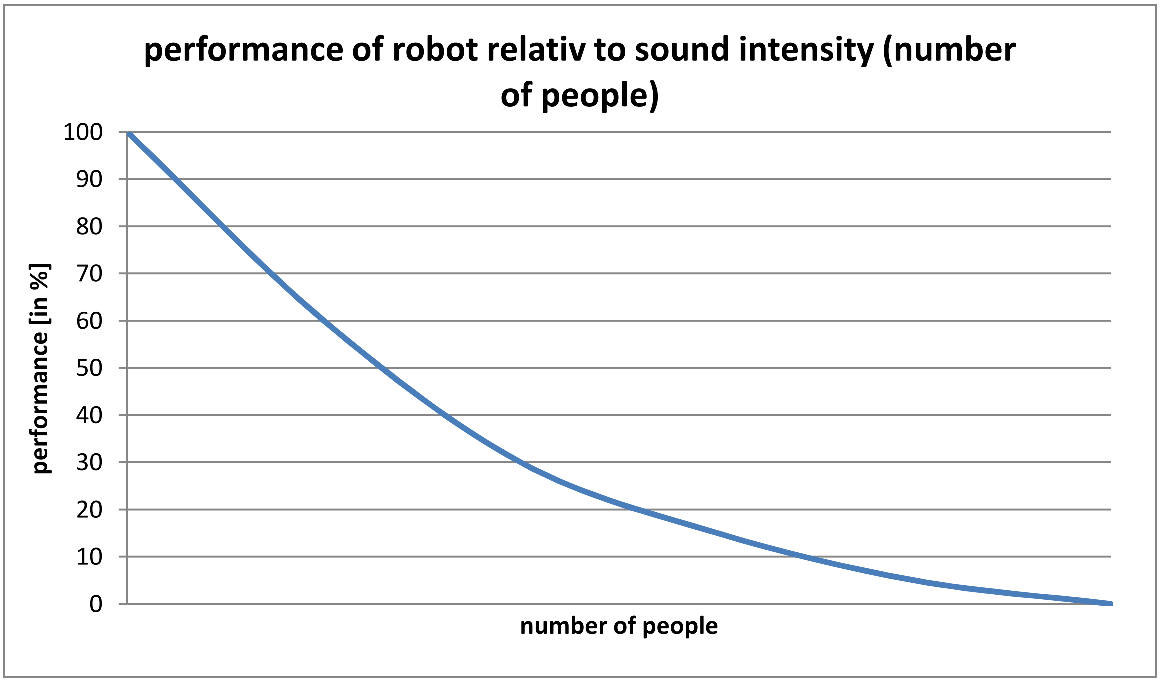
2.3.2.3 Edge detection

If the robot detects an edge, he will immediately stop driving. Afterwards, he checks the area behind him and if it's free, he will drive backwards a short distance. Then he checks the direction of 90° degre es and if there are no obstacles available, he makes a turn of 90°. If the re is still an edge available, he will repeat the turn of 90 degrees until no more edge is nearby. When the driveway is free the robot moves forward.

2.3.2.4 Performance

Performance of the robot:

- The performance of the robot depends on the sound intensity of the shopping mall. If the shopping street is very crowded, the sound intensity will increase. As a consequence the robot slows down the performance because he has to stop more often than in a normal operation mode. Regarding this fact people can easier pass by.
- If the street is nearly empty, there will be barely a noise. In this case the robot increases his performance by minimizing the required stops so he is able to do the cleaning work faster.



2.3.3 Safety analysis

2.3.3.1 Risk estimation

Hazard Identification for "CleanRob" in public usage

Type	Origin	Potential Consequences
Mechanical	Moving Robot	crushing hands, feed Impact on body Pushing away
	Rotating Wheels	Entanglement
Electrical	None (24V DC)	None
Physical	hot Surface caused by Battery (Li-Ion, Li-Po)	Burnings
	Hazard generated by vacuum	stress
	Robot falling	Crushed bones, death, major inner injuries
	Hazard generated by noise	stress
Chemical	Battery acids	Chemical burnings

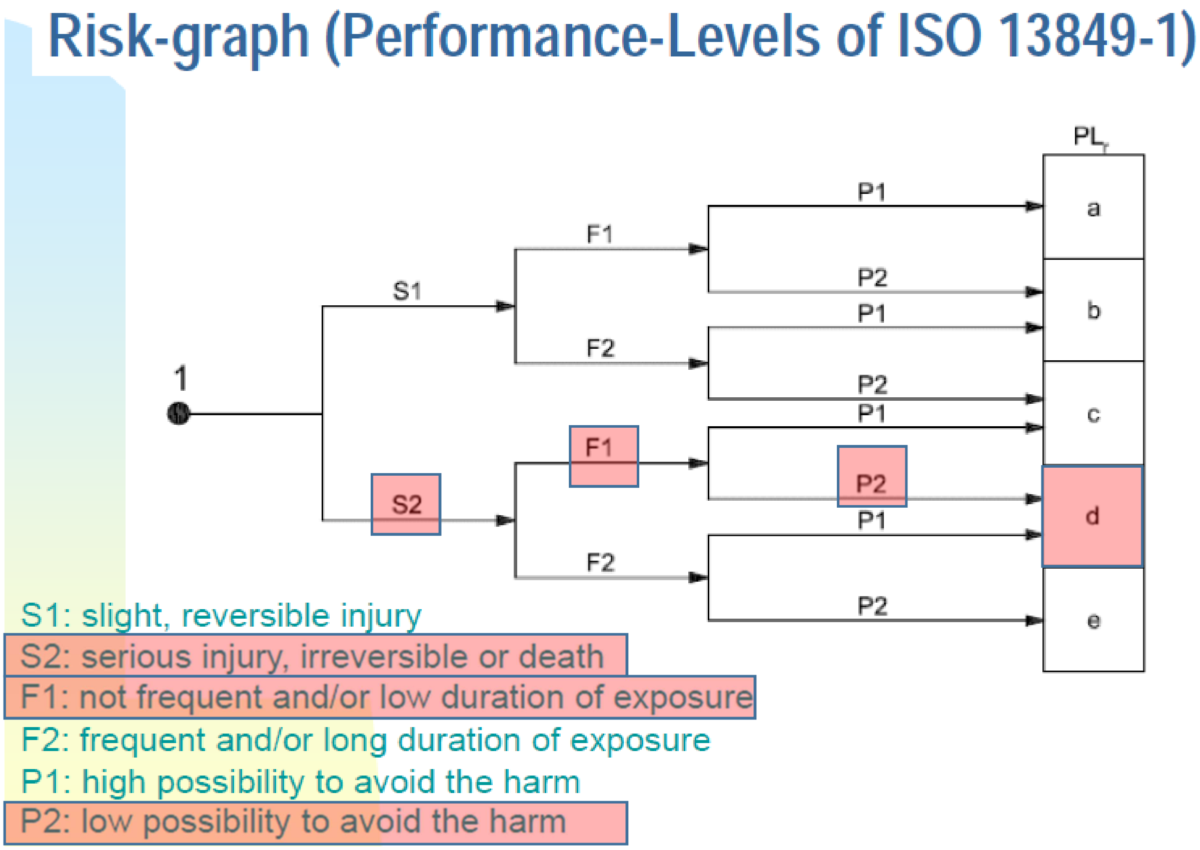
2.3.3.2 Risk Class Estimation

Frequency	Consequence			
	Catastrophic ***Very many people killed***	Critical ***Death to several people***	Marginal ***Serious permanent injury to one or more persons; death to one person***	Negligible ***Minor injury***
Frequent ***10^{-3}***	I	I	I	II
Probable ***10^{-4}***	I	I	II	III
Occasional ***10^{-5}***	I	II	III	III
Remote ***10^{-6}***	II	III	III	IV
Improbable ***10^{-7}***	III	III	IV	IV
Incredible ***10^{-8}***	IV	IV	IV	IV

Risk class	Interpretation
Class I	Intolerable risk
Class II	Undesirable risk, and tolerable only if risk reduction is impracticable or if the costs are grossly disproportionate to the improvement gained
Class III	Tolerable risk if the cost of risk reduction would exceed the improvement gained
Class IV	Negligible risk

2.3.3.3 Risk Reduction Estimation

2.3.3.3.1 Risk-graph

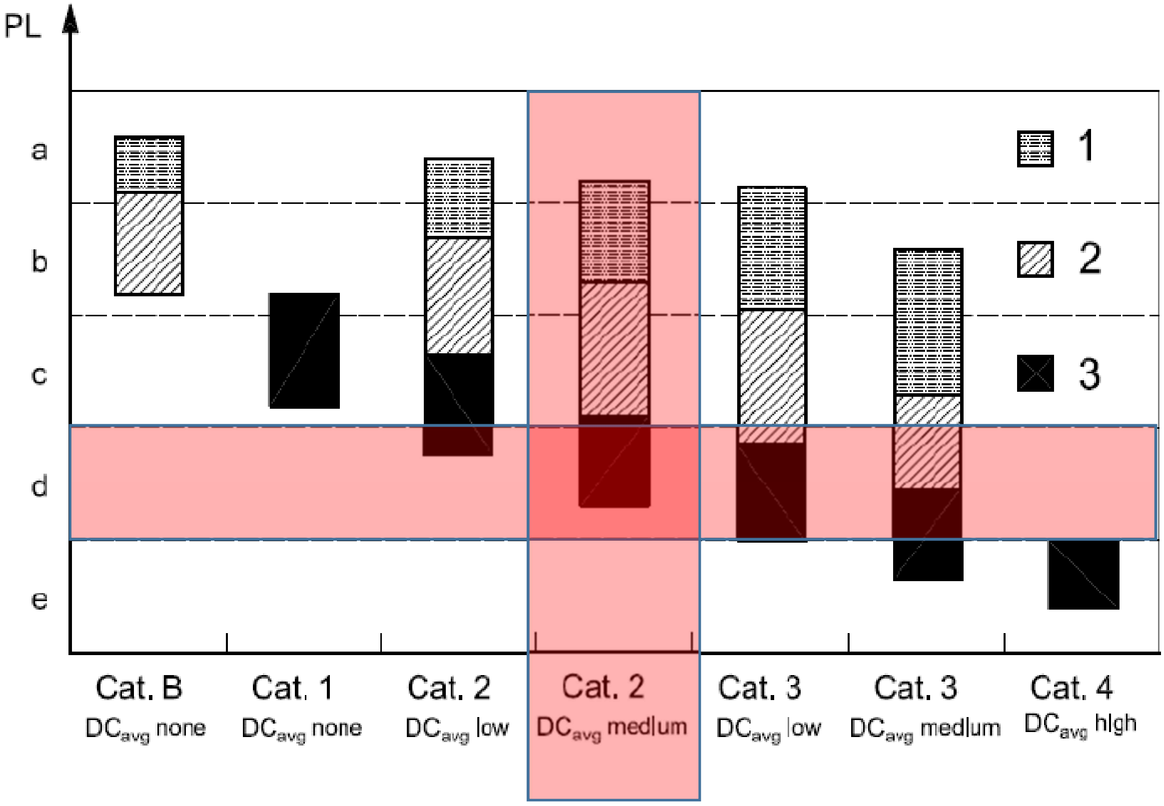


The robot is heavy and it is possible that it drops downstairs. The other hazards caused by it are not as hard, therefore less risk reduction would be ok. The worst case is the robot dropping downstairs and hitting somebody. Because of his heavy weight people could die (→ S2). But the robot is not always working too close to stairs, so the duration of exposure is rather low (→ F1). It is probably not possible to avoid the robot falling down the stairs (→ P2).

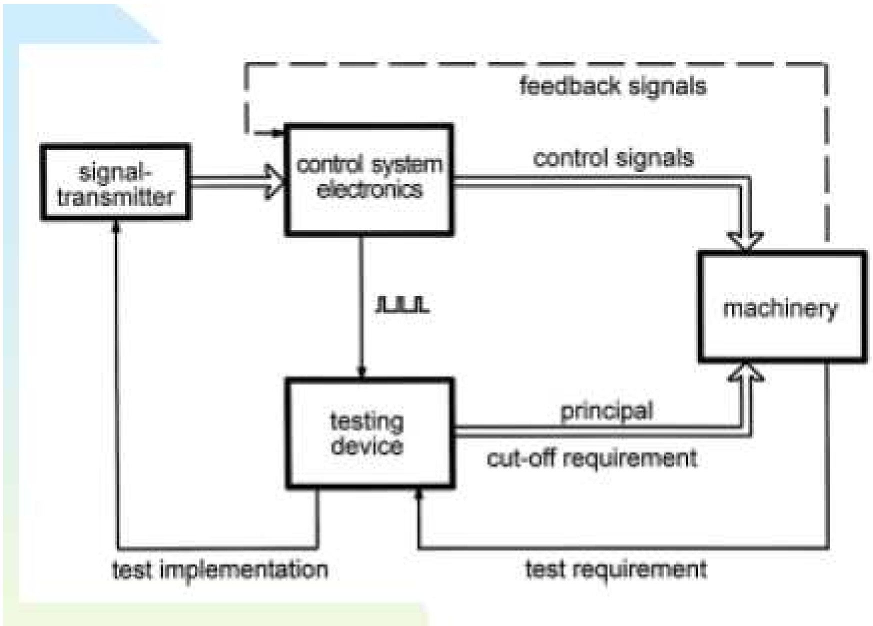
All in all performance level d is required (PL_r -> d)

2.3.3.3.2 Performance-Level and Category

Performance-Level and Category



There are several possibilities to get PLd. Therefore a Cat.2 control is required, combined with a high MTTFd (30-100 years) and at least 90% of all failures must be detected.

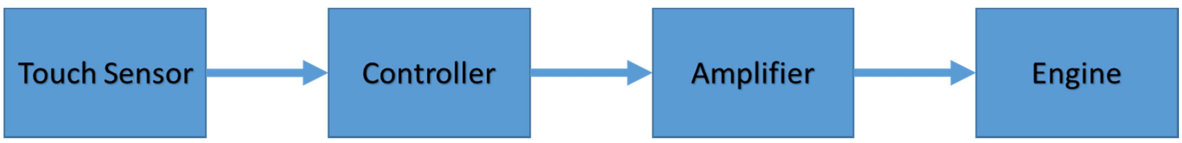


Example for a Cat.2 Control

2.3.3.3.3 Calculating Performance Level

For instance one sensor actuator chain with reduced complexity gets analyzed. The total analysis of the system is much more complicated. Therefore more information and mathematical calculations are required.

The chain shown below is probably the worst case scenario. The other sensors have a higher safety performance. The $MTTF_d$ value is much higher for non-contact applications.



2.3.3.3.4 Calculating $MTTF_d$

$$MTTF_d = \frac{1}{\lambda_S + \lambda_C + \lambda_A + \lambda_E}$$

$$\lambda_S = \frac{1}{MTTF_{d_S}} = \frac{0{,}1 * n_{op}}{B10_d} = \frac{0{,}1 * \frac{d_{op} * h_{op} * 3600}{t_{cycle}}}{B10_d} = \frac{0{,}1 * \frac{365 * 24 * 3600}{120}}{2000000} = 0{,}01314 \frac{failures}{a}$$

$$\lambda_C = \frac{1}{MTTF_{d_C}} = \frac{1}{153} = 0{,}006535948\ \frac{failures}{a}$$

$$\lambda_A = 50 * 10^{-9}\ \frac{failures}{h}$$

$$\lambda_E = \frac{1}{MTTF_{d_E}} = \frac{1}{200a} = 0{,}0005\ \frac{failures}{a}$$

$$MTTF_d = \frac{1}{\left(0{,}1314 + 0{,}0065 + \left(50 * \frac{10^{-9}}{8760}\right) + 0{,}005\right) * \frac{failures}{a}} \approx 40a$$

<u>Annotations:</u>

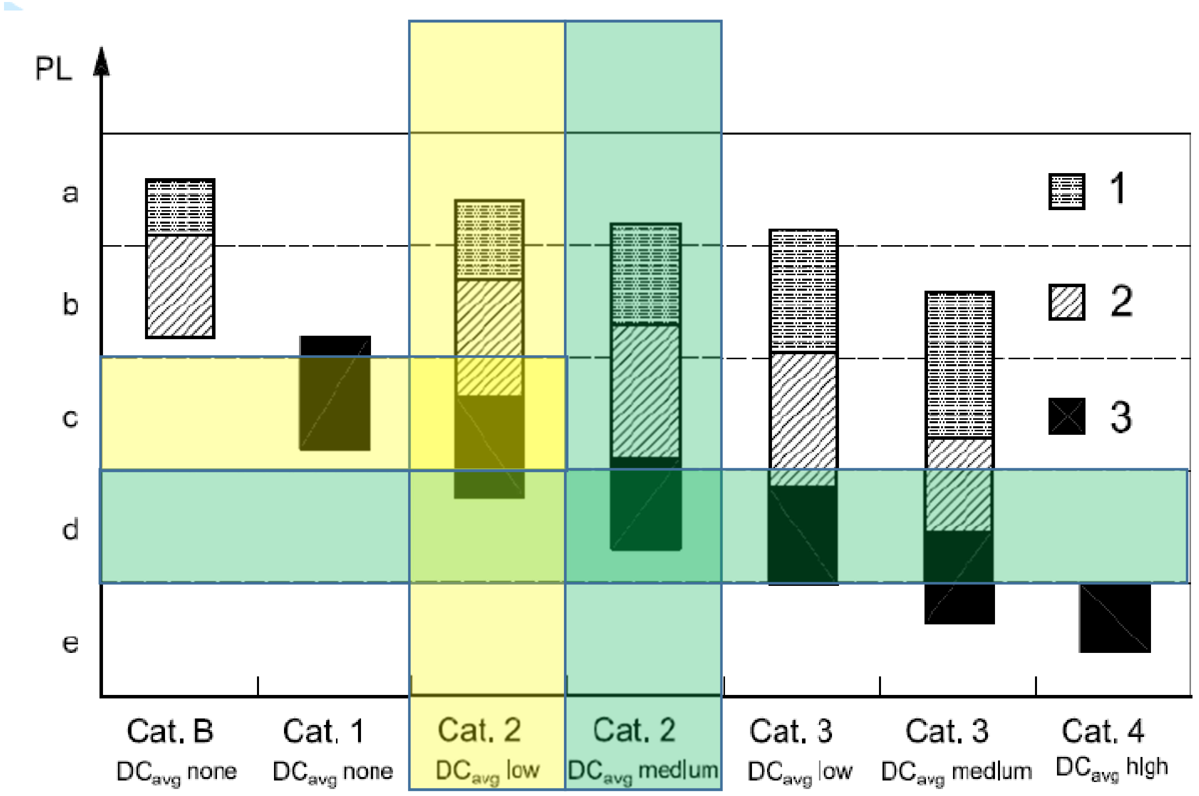
- B10d value for the touching sensor is a literature value for all mechanical touching sensors, the real value depends on the used sensor and must be looked up in the datasheet “Automatisierungstechnik – Norbert Becker”
- MTTFd of the Controller is a common value for all ATMEL controllers. ATMEL uses the MTBF, but for our calculation it is treated as the same http://support.atmel.com/bin/customer.exe?=&action=viewKbEntry&id=266
- Failure rate of the amplifier is a value found in a manufacturer document //section1_Power_Semiconductors_Basic_Operating_Principles_section2_Basics.pdf//Page 126
- MTTFd of the engine is estimated to fulfill specification!

2.3.3.3.5 Final Performance Level

We are using a CAT.2 control system with single channel solution. If the system is capable to detect at least 90% of all Errors per channel we achieve Performance Level d (PLd → green highlighted). If we detect only 60%, the system increases the safety only with Performance Level c (PLc → yellow highlighted) and some additional safety functions are required to get the necessary risk reduction.

Examples for technical realization concepts for SIL (IEC-61508)

SIL	PE logic syste m-Configuration	Diagnostic Coverage per channel	CCF ß	Mean Time to dang. Failure $MTTF_d$	CAT
-	Single PE, Single I/O	0%		5 Years	B
-	Dual PE, IPC, Dual I/O,1oo2	0 %	5 %	5 Years	?
1	Single PE, Single I, Ext. WD	60%		5 Years	2
	Single PE, Single I, Ext. WD	60 %		7.5/15/5 Years	2
	Dual PE, IPC, Dual I/O,1oo2	60 %	5 %	5 Years	3
	Dual PE, IPC, Dual I/O,1oo2	90 %	10 %	5 Years	3
	Dual PE, IPC, Dual I/O,1oo2	90 %	10 %	45/15/30 Years	3
2	Single PE, Single I, Ext. WD	90 %		5 Years	2
	Dual PE, IPC, Dual I/O,1oo2	90 %	1 %	5 Years	3
	Dual PE, IPC, Dual I/O,1oo2	90 %	1 %	7.5/15/5 Years	3
	Dual PE, IPC, Dual I/O,1oo2	90 %	5 %	10 Years	3
	Mixed, Dual I/O,1oo2	PE 30 %		5/50 Years	3
3	Single PE, Single I, Ext. WD	99 %		10 Years	2
	Dual PE, IPC, Dual I/O,1oo2	99 %	1 %	15 Years	4



Possible additional safety features:

- Use more sensors (redundancy and diversity)
- Implement a second cut off path with an electromechanical component (conductor)
- Implement an acceleration sensor to detect the falling robot and use a kind of airbag to protect the environment
- Use fail safe bus structure for communication

2.3.3.4 Robot FMEA

Robot FMEA								
FMEA:				Responsibility: SaSeRoS2013				
Product: Cleaning Robot 359				Prepared by: Simon Nolden				
Core team: Olga Fedtchenko, Epsen Rise Halstensen, Pascal Boeschoten, Kjeld Niewendijk, Vu Nguyen, Simon Nolden				Key Date: 18.04.2013				
Item	Function	Failure Mode	Failure Effect	Potential Failure Cause	Preventive Action	Detection Action	Recommended Actions	Responsible & Deadline
1	Touch Sensor	Sensor is always in activated mode (1)	No robot movement, no cleaning	mechanical impact on the sensor	cover sensor by design	manual check (daily)	write self-checking routine, write user instruction	
2	Touch Sensor	Sensor is always in deactivated mode (0)	No obstacle detection possible, insuries on humans or equiptment possible	mechanical impact on the sensor	cover sensor by design	manual check (daily), additional cyclic check when activated	write user instruction, write checking routine	
3	Touch Sensor	Sensor connection lost	No robot movement, no cleaning	damaged cable, plug out of sensor/controll er	safe cable routing	cyclic check on sensor signal (1), full check during maintenance	write self-checking routine, write maintenance instruction	
4	Light Sensor	Sensor shows wrong brightness value	edges are not detected	dirty sensor	clean sensor daily	manual check (daily)	add to user manual	
4	...	...	...	...	...	...	...	

5	Motor	No motor rotation	no movement	mecanical damaged	none	only on maintenance	none	
6	Motor	No motor rotation	no movement	cable connection lost	safe cable routing	only on maintenance	add motor to cable check routine in the maintenance instruction	
7	Driving Motor	Encoder Damaged	wrong speed/ direction indication	old sensor, mecanical impact, wire broken	safe design	compare results of left and right direction counter while moving straight on	write detection algorithm	
8	Overview Motor	Encoder Damaged	algorithm for detection free direction does not work properly	old sensor, mecanical impact, wire broken	safe design	detect if the robot often moves into a "free direction" an stops imediatly because there is a obstacle infront	write detection algorithm	

The FMEA shows an example of a few possible failures. The FMEA is not complete.

2.3.4 Test procedure

Starting robot

- Does the controll unit power up?
- Press the orange button and select the cleaning program, it should start its cleaning procedure.

Sensor test

- Does the bumpers react on inpact?
- Does the ultrasonic sensor react?
- Does the lightsensor react?
- Start the sensortest program.
- Press both bumpers, one at a time, the controll units should produce a beep each time.
- Place your hand in front of the ultrasonic sensor, the display should write out the distance.
- The lightsensor must be tested in a way that you have to lift up the robot or find a small edge, stairs equally high drops might be dangerous in case of an error/failure.

Operational test

- Start the robot(see "Starting robot").
- Place an object in front of the robot, does it avoid the object correctly?
- Does the ultrasonic move to search for a free direction?
- Does the robot react when we touch the bumpers at the front and back?
- Does the robot back up if it detects an edge or drop?
- The robot should drive straight forward if theres no oject in a close distance in front of it. Place an object in front of the robot, the robot should drive straight forward till it sees an object, then turn the ultrasonic sensor to find a viable direction and drive that way.
- When the robot hits a lower object, the bumpersensors should get pushed and the robot should stop, look for a viable direction and drive that way.
- When the robot drives towards an edge or a drop, the lightsensor should register the drop and have the robot reverse of there.
- Does the robot detect a failure in the system?
- Try to unplug one of the sensors.
- Does the robot initiate safe mode after a system failure

2.3.5 Behavior

2.3.5.1 Formal description of behavior in operation mode

In this section we will describe the robots behavior in the environment we envision.

- Start sequence
  - Robot is beeping
  - Random sensor test: every sensor has to be tested without a specific order

Objects and movement

- Detects an object in front of the robot
  - The robot stops
  - Starts to beep
  - Waits a couple of seconds to see if the object has moved
  - If gone, drives forward
  - Else, turns the ultrasonic sensor to look for a free direction
  - Drives in the desired direction
- Detects a low object like a hand by pushing front bumper
  - The robot stops immediately
  - Turns the ultrasonic sensor to look behind
  - If clear, move backwards 20 cm and
  - Check if the path is free with the ultrasonic sensor, if not search for a new path.
  - If the back bumper gets pushed during the move backwards, the robot will stop and enter safestate.
- If the rear bumper gets pushed while moving forward
  - Stop moving for a 2 seconds,
  - Start moving again
- Detection of a failed sensor

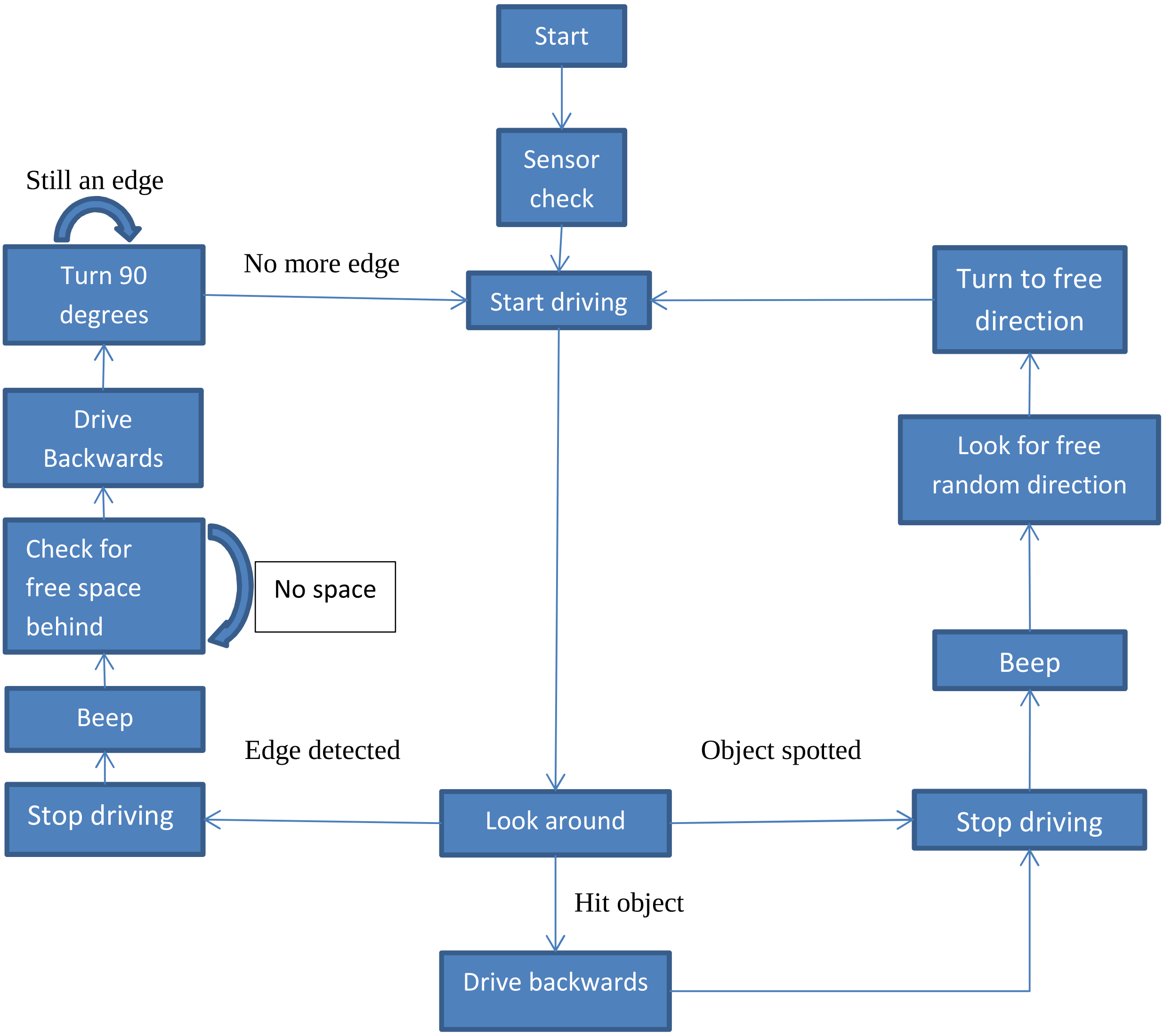
- Robot enters safestate

Safestate

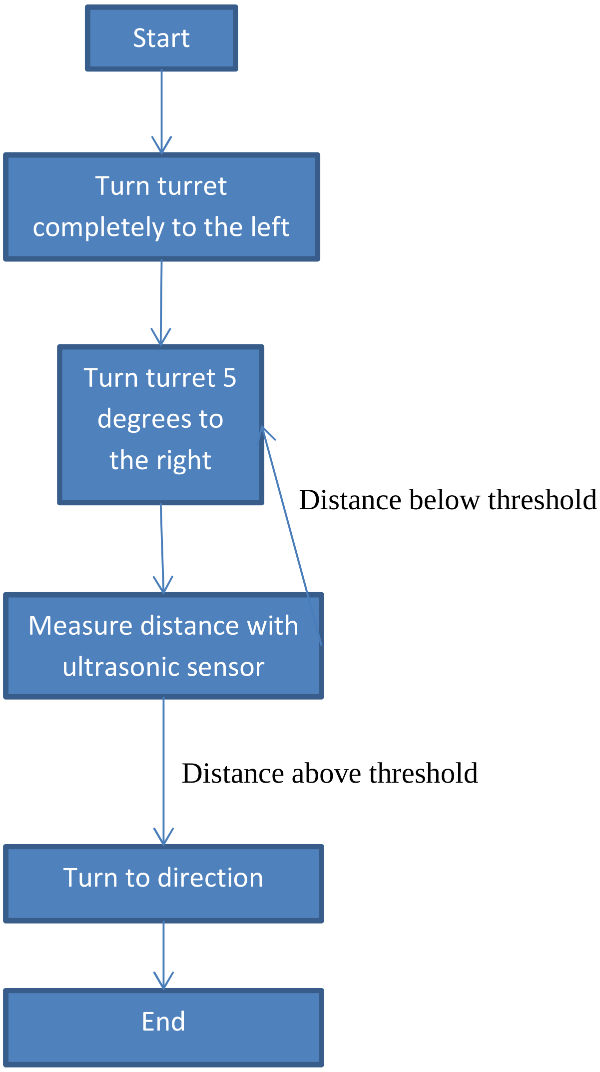
- Robot stops.
- Gives a beeping warning sound.
- Writes an error in the display.

Flowchart robot behavior

Overview



Looking for free direction & turn to free direction



3. User manual

3.1 Daily Use Instruction

You have to make sure that

- the dust box is empty
- the battery is charged
- the information is shown on the display
- there are no visible damages

Afterwards, you have to start the robot. Follow the sensor check instruction which is shown on the display.

3.2 Edge detection

If the robot detects an edge, he will immediately stop driving and starts to beep. Afterwards, he checks for a free space behind him. If there is a free space, he drives backwards. Then he makes a turn of 90 degrees. If there is still an edge available, he will repeat the turn of 90 degrees until no more edge is nearby. When the driveway is free the robot moves forward.

3.3 Empty / low battery

The operation of the robot is only possible if the battery's charging status is higher than 10 %. If there is less than 10% of the charging value left the robot will return to the charging station automatically. The number of available charging stations depends on the size of the shopping mall.

In case the robot isn't able to find a charging station within 5 minutes after the battery status was less than 10% the operator will receive a message on his mobile device.

If the operator doesn't arrive in time to charge the robot, it will run out of power during the operation. For that, the robot goes offline and stops so it won't be able to cause any harm to the approaching people.

3.4 Failing sensors

If the robot looks around and the system signals a sensor failure, the robot will stop driving and begins to beep.

3.5 Fallen robot

If the robot falls to the side or down the stairs, there will be no possibility to detect this failure. In this case, a possibility of damage to the robot and the floor exists. Furthermore, by falling down the robot might hurt one or more persons in immediate proximity.

3.6 Safety Instruction

- Handle with care.
- Don’t try to operate the robot if you are not an instructed person.
- Don’t put objects on the robot, because you might damage the sensors or other parts of the robot.
- Don’t slop a liquid on the robot.
- Don’t come too close to the robot while he does the cleaning operation.

4. Maintenance guide

4.1 Normal Maintenance

The following information will explain the instructed person who operates the robot how to maintain him in case of a malfunction.

In case, the robot doesn’t work correctly please check if all sensors are plugged in into the right ports. If that is the case, restart the robot. When he restarts he undergoes a sensor test. Hereby, you have to follow the instruction on the display of “CleanRob”. If the test was passed, the robot will work correctly. Otherwise, when the test was failed, the robot has to be brought to the maintenance.

The operator is neither allowed to do the maintenance on his own nor to manipulate technical parts like sensors which are placed on the robot.

A complete service of the robot is required every two years.

4.2 Error Caused Maintenance

If an error appears on the screen, you have to contact the service team under the following number:

+49 221 17906100