A safety concept for service-robots operating in nursing homes

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***Abstract*— The next years will put more and more focus on the application of service robots in elderly care, especially nursing homes, to meet the "elderly wave" and at the same time be able to provide high-level, individual care of the residents.**

However, new challenges appear when introducing service robots in an environment where residents with impaired cognitive skills, like dementia, coexist with the service robots. This, especially, due to the fact that the residents mostly <u>cannot</u>, and formally, <u>are not</u> responsible for themselves. Thus, any accident will per definition, be the robot's responsibility.

Unfortunately, there is a lack of standards and best practice about how to establish a safe and harmonic environment where dementia people and service robots coexist and collaborate. Unlike industrial robot installations, both the physical and interperceptual risks must be assessed when introducing service robots to nursing homes. This, because fear can cause unwanted reactions from residents, which in turn can create new risks.

This paper addresses the complexity of performing risk assessment for service robots operating in coexistence with dementia residents in nursing homes. Both physical and interperceptual risks are included. Based upon the traditional ISO analysis, an extended method is suggested to minimize the unavoidable, residual safety risk.

I. Introduction

"Robots" have always been associated with science fiction and supernatural skills. All the time since Karel Chapek introduced the word "robot" in his famous play, Rossum's Universal Robots, has the common exceptions to the capability of a robot been associated closely with the skills of the human.

This, even though, in the industrial world, the robot or normally, "industrial robot" has been accepted as a metal device working 24/7 and offering stable, high-quality manufacturing.

Traditionally, industrial robots had to operate within physical fences, however, during the last years, open factories have become popular due to the high flexibility and ability to utilize the synergy between the robot's and the human's skills [8]. However, a coexisting environment, has also required new knowledge about the perceived safety, and trust in automation, to avoid stress impact on the humans [5, 8]. This, in turn has created important knowledge needed to introduce robots in new areas, like elderly care [1, 3, 6, 7, 9, 10].

The current demographic development with "the elderly wave" forecast a huge lack of care givers during the next years. Only in a small country like Norway, with a population of 5,5 million people, it will be lack of more than 40 000 nurses in elderly care already in 2035 [11] due to the "elderly wave" (Figure **1**).

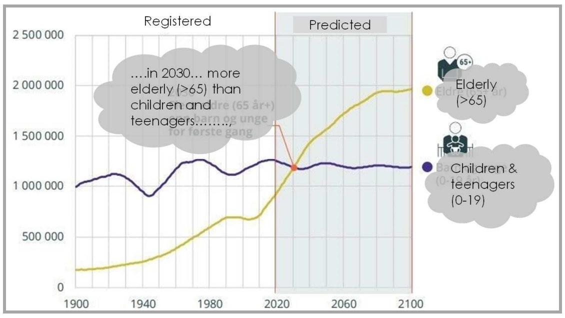

Figure 1"The elderly wave" in Norway [11]

In the European Union, it's expected to be almost 150 million people above 65 years old, by 2050. People between 75 and 84 years old, is expected to have the high highest expansion growth and even very old people, above 85 years old, is expected to increase with more than 130% [7].

Additionally, the standard in nursing homes, develops towards individualized, on-demand based services, which requires even more resources to be fulfilled [12].

The application of modern IT and robot technology are among the few measures that can solve the resource challenge in the elderly care. A smart utilization of this, will release more time for value added work; hence, care and medical treatment of the residents.

This has led to a request for a new generation service robots that are designed to operate in nursing homes, within the same, open environment as the care givers and the residents. This puts however, strong requirements on the safety and the robot's ability to understand the social interactions with the residents; especially those with dementia.

Figure 2 Service robots will be a important resource in nursing homes

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It's expected that the service robots will have an important role as a contributing, integrated resource in the future's nursing homes (Figure **2**). However, important questions have been raised about how the safety requirements, since the nursing homes represent an open environment where most people are suffering from impaired cognitive skills, like dementia. As a result, the residents may have unexpected reactions, and even be frightened by the service robot.

Thus, even though the service robot is certified according to an existing standard, like the EN ISO 13482 [13] and is intended to operate safely in an open environment, like a restaurant, the same service robot is not necessarily applicable in a nursing home.

II. SAFETY IS NOT JUST ABOUT STOPPING THE ROBOT

Safety is an essential property of daily life given its critical role in being one of the fundamental needs of human beings. Since robotic systems should be designed without compromising human safety, there is a plethora of research on physical safety in human-robot interaction, HRI [2, 4, 5].

Physical safety

Basically, the physical robot safety, required one of the two basic requirements to be fulfilled [13]:

- All safety related hardware and software must be fail-safe, in practice *redundant*
- Alternatively, the robot must be *intrinsically safe*, which is normally solved by limiting the performance of the servo motors

Furthermore, it's also required that people behave reasonable, like e.g.

- Not climbing over or under the fences covering the robot !
- Not running, or walking faster than 1.8m/s !

If conditions like these are violated, any accident is formally defined as the human's responsibility. Such conditions cannot be required by the residents in a nursing home because they mostly have impaired cognitive skills and are not, according to the law, responsible for themselves.

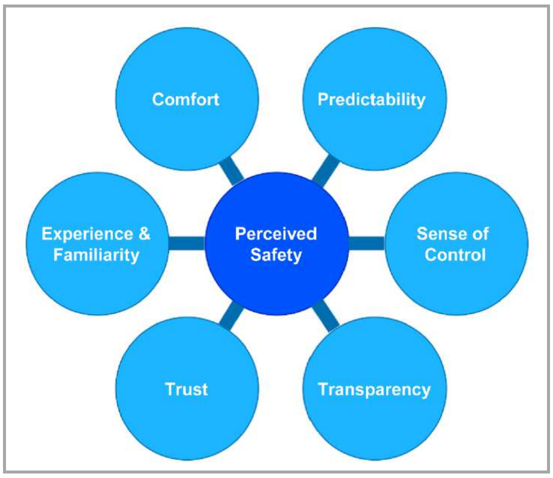

Figure 3 Perceived safety [5]

Thus, formally, the service robot provider will be responsible in case the robot harms any.

Operating in nursing homes, may also require other risks to be assessed, like

- Walking sticks may not be detected by the safety lasers, due to dead zones.
- The residents may lean on the robot, when passing it. However, if the robot starts moving, they may lose their balance and fall.
- A patient lying on the floor may not be detected because he is under the scanning zone of the safety lasers.

Additionally, the severity of a fall may be serious for elderly people because they have a brittle bone structure. Thus, a fall gives a considerable risk of a hip or femur neck fracture.

Perceived safety

Even though the physical safety requirements are fully satisfied, the introduction of robots can still have a negative stress effect on people due to their perception of the robot as an unsafe or scaring device. From [5] the perceived safety includes the following factors (Figure **3**):

- *Comfort*: The psychological impact of the robot's behavior on the human
- *Predictability*: To which extend the robot behaves as expected
- *Sense of control*: That the human feels confident that the robot obeys
- *Transparency*: That the robot has a physical feature communicating its safety functions
- *Trust*: That the robot is fail-safe and does not do anything unexpected
- *Experience*: The aggregated cognitive understanding of the robot's behavior and which potential risk situations may arise

Traditionally, a good, perceived safety is normally being established by educating the humans, that are interacting with the robot. However, in a nursing home, both the care givers and the residents, ideally should be trained, however this is challenging, because

- Most of the residents have impaired cognitive skills, such as dementia, which prevents learning and memorization. Thus, even if the training was successful, they would most likely forget everything until the next day.
- Care givers are naturally more likely to focus on care, rather than learning about new technology. This makes the training process slow.
- Absence due to illness, the use of temporary staff and turnover is often significant, which makes it challenging to maintain competence from the training over time.

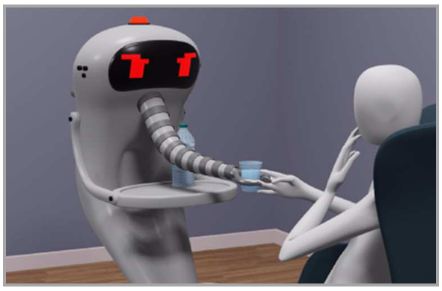

Figure 4 Providing services requires physical proximity to people

This, in turn, gives an environment where the perceived safety is determined by the persons' immediate perception of the service robot; rather than trust that is gradually built up over time.

Task and interperceptual safety challenges

The desired operation conditions may sometimes be contradictive to the desired level of perceived safety, like

- The service robot must operate near the residents to perform a service task (Figure **4**)
- Highest, possible motion speed is desired during transport and task execution, utilize the service robot
- The robot must stop immediately, in case of potential collisions, but this can have an adverse shock effect, especially on an elderly person

Additionally, when operating in a shared environment with dementia residents, sometimes unexpected human behaviour occurs. This is because the residents' mood and perception vary from time to time, and even during the implementation of a well-known task, an unfortunate stressful situation can arise. E.g., a resident may react spontaneously and throw a glass of water over the robot, which may cause a malfunction in the safety system if the robot is not waterproof.

Similarly, in the event of even a non-dramatic, immediate safety stop of the robot, a residents may suddenly be startled, lose the balance, and fall to the floor.

These cases represent a class of risks, which are created at the intersection between physical and perceived safety. This challenges the traditional risk assessment method, which exclusively takes physical safety into account.

Currently, there is significant R&D and standardization work going for mobile robots both in industry and health care [2, 4, 14, 16]. Currently, however, service robots are mainly deployed in nursing homes on the understanding that there will still be an unavoidable residual safety risk.

III. Safety Requirements

Requirements to the robot

All products sold within the EU must be certified according to the CE standard and marked with the CE symbol, demonstrating that the manufacturer has checked that the product complies with The Machinery Directive [18]. Additionally, a risk assessment will need to be performed, according to ISO 12100 [17].

Probability class	Frequency	Consequence class	Consequence
5	10 times per year or more frequent	5	Very serious personal injury or death
4	Once per year or more frequent	4	Serious personal injury with possible permanent disability
3	Once per 5 year or more frequent	3	Moderately serious personal injury (> 14 days absence)
2	Once per 10 year or more frequent	2	Less serious personal injury (< 14 days absence)
1	Rarer than once per 10 years	1	Minor personal injury

Figure 5 Risk classes for robot safety

A robot shall be designed according to the following principles to avoid hazards [17]

- *Inherently* safe design (first priority)
- *Protective* measures (second priority)
- *Information* for use (if a) and b) are not possible to implement

However, additional standards like ISO 13482 [13], can be applied to fulfil the safety requirements for service robots used in personal applications. This standard contains the extent to which hazards, dangerous situations or dangerous incidents are covered in an environment where humans and robots coexist or cooperate.

For a stand-alone service robot, the compliance with these directives, normally ensures the required safety. However, operating a service robot in a nursing home, introduces additional safety challenges.

Safety in the application of the robot

The implementation of service robots in nursing homes, may create new risk scenarios and ethical considerations [1]. Thus, a risk assessment, to analyse the application scenarios, must be accomplished. A proper method is described in [17].

This method is based on the identification and analysis of the various risk scenarios during the operation of the robot. The cases are then assessed according to frequency and consequence, which are combined and made visible with colours, to visualize the severity (Figure **5**, **6**, **7**).

Consequence	1	2	3	4	5
Probability	Minor personal injury	Less serious personal injury	Moderately serious personal injury	Serious personal injury	Very serious personal injury or death
5 ≥ 10 times / year	5	10	15	20	25
4 ≥ 1 times / year	4	8	12	16	20
3 ≥ 1 times / year	3	6	9	12	15
2 ≥ 1 times / year	2	4	6	8	10
0 < 1 time / year	1	2	3	4	5

Figure 6 Risk evaluation as a part of the risk assessment

Result	Consequence
≥ 10	Not acceptable. Measures must be taken to reduce the risk
5 – 9	Measures to be considered to reduce the risk
≤ 4	Risk level acceptable

Figure 7 Required actions as outcome of the risk assessment

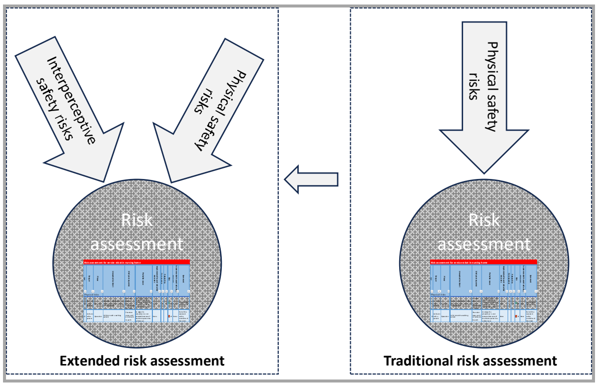

Figure 8 Including interperceptive risks in the risk

The risk assessment has traditionally not had a strong focus on the perceived safety. However, according to the previous examples, the risk assessment for service robots operating in nursing homes, required an extended risk assessment (Figure **8**). This also includes the interperceptual risks, thus, risks that have arisen due misperceptions of the robot's intent.

The risk assessment, containing all identified cases, is summarized in a structured way, demonstrating that the process has been professionally carried out (Figure **9**). This table may also serve as an important background document in case of any legal assessment, due to an injury.

IV. A GENTLER COEXISTENCE BETWEEN HUMANS AND SERVICE ROBOTS

The project, SAM4ROB [19], focused on how to create a working environment, where humans and robots could coexist and collaborate in harmony and synergy. The project was targeting industrial purposes, however, mostly, the same, basic principles apply when introducing service robots in nursing homes.

Safety and perceived safety requirements are be satisfied by introducing *Safety Measures*, and *Risk Preventing Measures*.

Risk assesement for service robot in nursing home

Danger	Phase	Unwanted incident	Likely consequence	Probable cause	Implemented hazard reduction measures	Consequence	Probability	Risk	Recommended hazard reduction measures	Comment
Collision with a patient	Operation	The robot crashes with the walking stick of a standing / moving patient	Fall and physical patient injuries (hip fracture)	A walking stick is not detected because a standing resident has placed it in a blind spot on the safety laser.	None	4	3	12	None	Unavoidable residual risk
Collision with a patient	Operation	Collision with a walking patient	The robot stops and / or redirects its path	Potential collision between a walking resident and a moving robot	None	0	0	0	None	Part of the standard safety controller of the robot
Crushing hazard	Operation	Collision with a wheelchair that the resident is sitting in. The resident's hand is crushed between the robot and the edge of the wheelchair	A little pain in the patient's hand	An edge of a wheelchair is not detected because of the blind spot on the safety laser.	Limited power on the robot's motors	1	4	4	None	Tests have been carried out to ensure that the pain is insignificant
Unexpected motion	Operation	The robot starts moving when a resident is leaning on the robot's body	Fall and physical patient injuries (hip fracture)	There is no contact detection on the robot's body	None	4	3	12	AIRSKIN	AIRSKIN guarantees physical detection of the human
...	...	...	...	...	...	...	...	...	...	...

Figure 9 A structured risk assessment (example)

Proactive Risk Prevention Measure : Acquisition of knowledge on beforehand, about potential situations, to provide a natural behavior to avoid possible safety conflicts. (e.g. Education to get the driving license)

Reactive Risk Prevention Measure: Upfront notification about a potential safety conflict (e.g., short distance to the next car); Traffic sign recognition (automatic speed adjustment)

Figure 10 Risk preventing measures (examples)

The Safety Measures are categorized as follows:

- *Reactive*: Immediate actions, which guarantee protection against personal injury
- *Proactive*: Pre-emptive measures, which guarantee to reduce the consequences of an imminent security conflict
- *Preventive*: Pre-emptive measures, guarantee to remove possible safety conflicts that may arise

Similarly, the *Risk Preventing Measures*, include

- *Reactive*: Provide information / notification to the person about risks and subsequent safety measures about to be activated
- *Proactive*: Educate / train the person to behave naturally in a way that reduces the risk of accidents occurring

Examples of safety measures and risk prevention measures related to daily driving are shown in Figure **10** and Figure **11**.

The practical implementation of this concept is done by dividing the area around the robot into different zones, which are connected to the respective safety and risk preventing measures (Figure **12**).

- *Danger Zone* (Reactive safety): Safety measures MUST be implemented to prevent any injuries of humans in case of safety conflicts; Typical action: Stop the robot
- *Warning Zone(s)* (Proactive safety): The safety measures are adapted to the risk for injuries; Typical action: Reduce the robot's speed when a person approaches the robot
- *Notification Zone(s)* (Reactive risk prevention): When the zone is entered crossed, a notification is given to warn the person that he soon will release a safety function; Typical action: Play a short tone

Preventive Safety Measure: Upfront, temporary reorganization of a dangerous area, into a safe area. Initiated by upfront information about a potential safety conflict. (e.g., Forced stop of the car because of a predicted safety conflicts e.g., school children standing next to a pedestrian crossing)

Proactive Safety Measure: Measures to reduce the consequence of a safety conflict (e.g., normal breaking in advance)

Reactive Safety Measure: A safety action, when the safety conflict occurs (e.g., immediate manual breaking, bumper, automatic emergency breaking)

Figure 11 Safety measures (examples)

- *Social Zone* (Proactive risk prevention): Train the person about potential safety risks, and the robot's ability to react; Typical action: Demonstrate a full emergency stop of the robot the first time in the morning a person enters this zone.

By implementing the zone-related actions in an event handler (Figure **13**), various actions can be easily implemented to comply with the required level of physical and perceived safety.

V. Risk Trade-offs

In a nursing home, the service robots must accomplish multiple tasks like logistics, services, observations, entertainment, communication etc. to be fully utilized. Thus, the robot will have different roles, and must also pretend to have different personalities (Figure **14**).

Typically, will a service robot, which is doing observations, move slowly, and try to avoid disturbing the residents, to get neutral observations. Therefore, observation is a simple, low-risk task to perform in a nursing home.

However, a service robot performing logistic tasks, needs to operate with a comparably high motion speed, to be productive. In this case, there is an unavoidable risk that the robot will be perceived as a bit scary by the residents. In addition, a relatively high speed will require a more brutal stop of the robot to avoid physical collisions. This may frighten the residents, and cause imbalance, falls and potential injury.

When offering services, there will be a need for the service robot to act in two different roles. At first it gently offers, for example, a glass of water. However, if the resident refuses, it may be beneficial to change the robot's behaviour to become a Supervisor, and thus, somewhat more assertive and authoritarian to convince the resident to drink.

This supervisor role may challenge the resident's perception of the robot and create a risk for an unexpected reaction like hitting the robot or spoil the glass of water over the robot's body. Without physically protected and waterproof body, the consequence maybe malfunctioning robot, or even worse, malfunctioning the safety functions.

A service robot offering physical training has the role to guide the resident through various exercises on e.g., a daily basis.

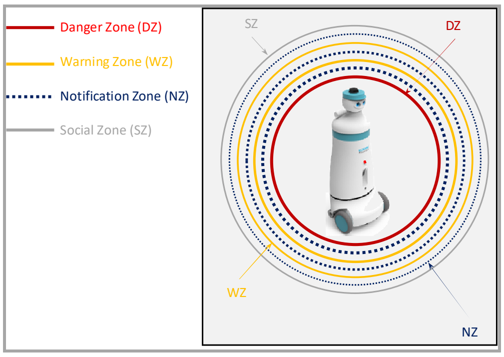

Figure 12 The zones defining the safety and risk prevention measures

INCIDENT HANDLING

Zone	Incident	Incident Code	Condition(s)	Action	Safety related
Social	Entering zone	SE	Instant activation 1-2 times per day	Sound, and demonstration of robot behavior	No
	Exiting zone	SX	No	No	No
Notifcation (s)	Entering zone	NE	Instant activation	Combined sound	No
	Exiting zone	NX	Instant deactivation	No	No
Warning (s)	Entering zone	WE	Instant activation	Slow down the robot gradually	Yes
	Exiting zone	WX	Instant deactivation	Short sound	Yes
Danger	Entering zone	DE	Instant activation	Stop the robot	Yes
	Exiting zone	DX	Instant / timer based deactivation	Short sound, and restart of the robot	Yes

Figure 13 The incident handler (example)

The robot is then physically in direct contact and interaction with the resident. In addition, the intention of an exercise program is to challenge, at least slightly, the resident's physical capacity and abilities, which can create a risk of falls and a potential injury.

These are only a few examples that show the complex balance between the desired function of the service robot, and sometimes inevitably increased risk of potential accidents. Good local knowledge of the physical and mental condition of the residents of the nursing home is, of course, crucial to finding the right balance.

VI. Conclusion

The introduction of service robots in nursing homes creates new challenges related to the robot's physical and perceived safety. This, since most of the residents hosted in a nursing home, have impaired cognitive skills, like dementia, and are not capable of being responsible for themselves.

Both from a practical and a formal point of view, the service robot will be responsible for the outcome of a collision or another safety conflict. Due to consequences of e.g., a fall to the floor with a likely hip or femur neck fracture, it's obvious that safety must be considered even more seriously and for industrial robot applications.

Additionally, the risk assessment must also include analysis of risks created by triggering of negative reaction by the dementia residents due to misperception of the robot.

Thus, the presented concept consists of assessments related to physical and interperceptual risks are considered.

The paper also includes a new approach about how increase the perceived safety, when implementing a service robot into a share environment like a nursing home.

However, it is almost impossible to remove all kinds of risks, will consequently, be a certain residual risk for accidents when introducing service robots in nursing homes.

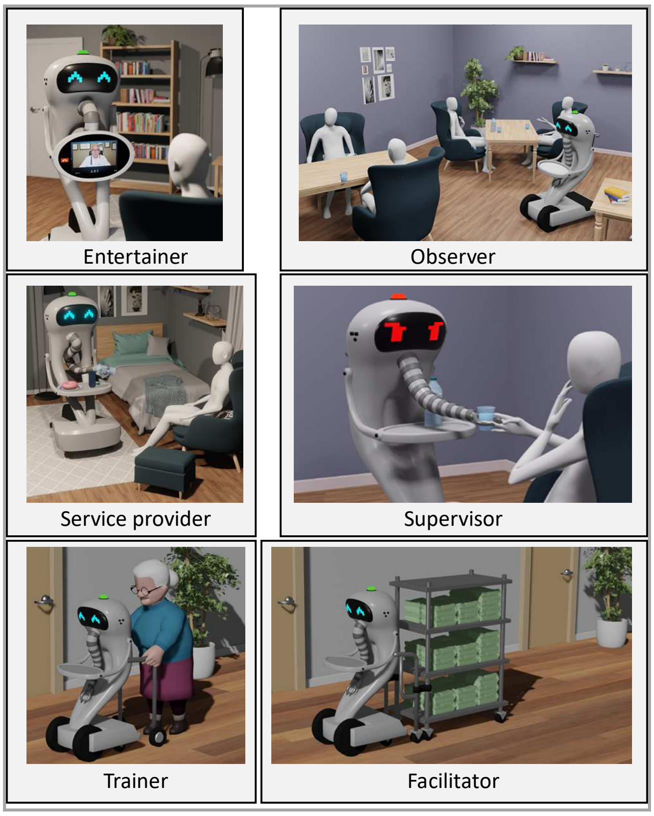

Figure 14 Different roles of the service robot in the nursing home

The aim is to reduce this to a minimum, to establish an environment where the care givers and the residents can coexist in harmony and synergy with the robot. With this, hopefully soon, "a robot wave" can come in and solve the challenge of "the elderly wave".

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