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Preface

This research project ROSE¹ was funded by the Academy of Finland, Strategic Research Council, decision #292980. Please note that *Robot Rose*² in the Netherlands is a separated activity and not related to the Finnish ROSE activity.

Wikipedia.org is used in the publication frequently to explain concepts, words and phrases. Please note that Wikipedia and its content change continuously and are partially based on the opinions of individuals. However, Wikipedia is also a useful collection of further reading material for the interested reader.

As robotics and automation in care change and evolve continuously and at a growing rate, due to considerable business interest, they are also widely discussed. The companies wishing to participate in evolving markets frequently send marketing oriented press releases, which are published in a wide variety of web news and more official papers. Such news is also used and links are given in this paper as footnotes. The dates mentioned are the dates of web site access. The validity of most of the web pages has been checked by using several sources and engineering knowledge.

It was noticed during the work that elderly care is a very hot topic globally, and many related services and products are in the development phase, although no major breakthrough have yet been made.

Espoo, 5th June, 2017

Hannu Lehtinen

¹ <http://roseproject.aalto.fi/en/>, 5th Sept., 2016

² <http://robot-rose.com/?lang=en>, 5th Sept., 2016

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Abstract
Tiivistelmä

1. Introduction

This publication provides robot and robot business related background data for the introduction of robot automation to benefit elderly care. The same methods can also be applied to the care of handicapped persons.

As robot technologies continue to improve and evolve in a rapid manner, more stress will be put on future and emerging technologies, which can well be applied to elderly care.

The number of elderly people is rapidly increasing, at least partly due to the success of medical care and improving health care networks. There is however a lack of personnel for elderly care related work in many industrialised countries.

Robot automation for elderly care and extended home living is a fashionable topic in the robot research community, see for example the review of Pearce et al. (2012). Furthermore, it is quite likely that robot automation will be relevant in the future in elderly care. Sharkey & Sharkey (2012) concluded this rather nicely:

“If introduced with foresight and careful guidelines, robots and robotic technology could improve the lives of the elderly, reducing their dependence, and creating more opportunities for social interaction.”

Healthcare robots are already a considerable business. The viability of the market and its development prospects are indicated by dedicated news sites e.g. Robohub³. “Assistive Robotics” is one of the most attractive sectors in medical technologies visualised in the Figure 1 below by Frost & Sullivan (N.N., 2016G).

Robots are not a single overall solution to the problems of elderly care. All widely exploited technologies need support from background systems and human societies, e.g. maintenance personnel and software updates. Robots – or phones and tablets – can be the interface between measurements of vital signals and health analysis software for doctors. For example, automated health-related activity supervision of elderly people has lucrative market opportunities and future prospects.

³ <http://robohub.org/topic/Health-Medicine/>, 6th June, 2017

We all wish to stay at home as long as possible. This is also the goal of all health care administration professionals, and is among the most economically feasible solutions for societies. Thus, there is clearly a common goal for all stakeholders.

The US roadmap on robotics (N.N., 2016D) says:

*“In order to **maximize quality of life** and to minimize the cost of care, a commonly agreed upon paradigm is to promote **aging in place**, where older adults can live at home provided that they receive some medical or service-related supplemental care. In this case, a person might need some help with light housework, decision support related to medical matters (medication management, nutrition, exercise regiment, etc.), or a conduit for improved social contact with the outside world. A robot can be utilized in these scenarios to perform service tasks, ...act as social mediator ... telepresence ...”*

Smart homes with robots integrated to the home automation system can do a lot more than robots as such. Doors would open as needed when the robot got close to the door. Ventilation would keep the temperature and oxygen content ideal for the persons in the room.

Societies are currently changing rapidly. The relevance of ownership will be reduced. Automated cars are being introduced. How these changes may affect elderly care is outlined in this report.

The main difficulty in new technologies is the cost of technology and application development to the level accepted and allowed to be delivered to markets. The essence is in selecting carefully what is developed, how it is used and how the evolving society and systems support the technology. This report was written to support this selection.

As a wide variation of robot technologies can be used in elderly care, and the technologies are evolving continuously, links to illustrative examples are given below (Table 2). The tasks and services which these robot automation devices and systems perform vary and the systems are being improved continuously. Therefore, a coarse classification of services is given immediately below (Table 1). Several robots perform several tasks (Table 2).

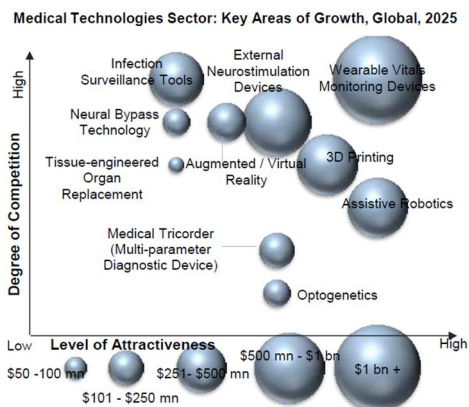


Figure 1 Most interesting medical technology markets (N.N., 2016G)

Table 1 Coarse care robot task classification

Short	Meaning
A	Assistive arm
C	Patient carrying
CO	Companion
D	Delivery
E	Edutainment
EN	Endoscopic
EX	Exoskeleton
F	Feeding
L	Patient lifting
PR	Prosthetics
PT	Physically therapeutic
S	Surgical
SA	Socially assistive
T	Therapeutic
TP	Telepresence

Table 2 Care robot examples

Name	By	Task	Link
iARM	Assistive Innovations, Netherlands	A	http://assistive-innovations.com/en/robotic-arms/iarm
HSR	Toyota, Japan	A, D, TP	http://www.toyota-global.com/innovation/partner_robot/family_2.html
Rose	Rose B.V.	A, TP	http://robot-rose.com/?lang=en
SerBot	Hstar Technologies, USA	A, TP, CO	http://www.hstartech.com/index.php/serbot.html
Resyone	Panasonic, Japan	C	http://robotcare.jp/?page_id=853&lang=en & http://news.panasonic.com/global/topics/2014/26411.html
PaPeRo	NEC, Japan	CO, SA	http://jpn.nec.com/robot/en/functions/index.html
REEM	PAL Robotics, Spain	D, SA, TP	http://pal-robotics.com/en/products/reem/
PALRO	Fujisoft, Japan	E, CO	https://palro.jp/
ARES	Auris Surgical Robotics	EN	http://spectrum.ieee.org/the-human-os/biomedical/devices/first-surgical-robot-from-secretive-startup-auris-cleared-for-use
My Spoon	SECOM, Japan	F	http://www.secom.co.jp/english/myspoon/

Bestic	Bestic	F	http://www.bestic.se/en/products/bestic/specifications/
Partner	Mealtime Partners, USA	F	http://www.mealtimepartners.com/description/description.htm
RIBA	RIKEN, Japan	L, C	http://rtc.nagoya.riken.jp/RIBA/index-e.html
RoNA	Hstar Technologies, USA	L, C, TP, CO	http://www.hstartech.com/index.php/rona.html
RehaBot	Hstar Technologies, USA	PT	http://www.hstartech.com/index.php/rehabot.html
Lokomat	Hocoma, USA	PT	https://www.hocoma.com/usa/us/products/lokomat/
Hand of Hope	Rehab-Robotics, China	PT	http://www.rehab-robotics.com/hoh/index.html
Gloreha	Gloreha, Italy	PT	http://www.gloreha.com
ALEx	Wearable Robotics, Italy	PT	http://www.wearable-robotics.com/kinetek/
Ekso GT	Ekso Bionics, USA	PR, EX, PT	http://eksobionics.com/healthcare/patients/
Cyberdyne HAL	CYBERDYNE, Japan	PR, EX, PT	http://www.cyberdyne.jp/english/index.html
ReWalk	ReWalk Robotics, USA	PR, EX, PT	http://rewalk.com/rewalk-personal-3/
Walk Assist	Toyota, Japan	PR, PT	http://www.toyota-global.com/innovation/partner_robot/family_2.html#h203
REX	REX Bionics, New Zealand	PR, EX, PT	http://www.rexbionics.com
MyoPro	MyoMo, USA	PR, EX, PT	http://myomo.com/
Indego	Parker Hannifin	PR, EX	http://www.indego.com/indego/en/Indego-Personal
Walking Assist	Honda, Japan	PR, EX	http://www.honda.com/mobility/walking-assist-technology
i-limb	Touch Bionics, USA, UK	PR, EX	http://www.touchbionics.com/products/how-i-limb-works
Guardian	Sarcos, USA	PR, EX	http://www.sarcos.com/?page_id=1369
AlterG Bionic Leg	AlterG, USA	PT, EX	http://www.alterg.com/products/bionic-leg/professional-physical-therapy

Bionic Hands	Open Bionics, USA	PR	https://www.openbionics.com/about/
Power Knee	Össur, Island	PR	https://www.ossur.com/prosthetic-solutions/products/dynamic-solutions/power-knee
Proficio	Barrett Medical, USA	PT	http://www.barrettmedical.com/pictures
da Vinci	Intuitive Surgical, USA	S, EN	http://www.intuitivesurgical.com/
REEM-C	PAL Robotics, Spain	SA, TP, A	http://pal-robotics.com/en/products/reem-c/
Paro	PARO Robots, Japan	T	http://www.parorobots.com/
Nao	Softbank Robotics, Japan	T, SA, TP	https://www.ald.softbankrobotics.com/en/cool-robots/nao
VGo	VGo	TP	http://www.vgocom.com/
Double	Double Robotics, USA	TP	http://www.doublerobotics.com/
Care O Bot	Fraunhofer IPA	TP, A, D	http://www.care-o-bot.de/en/care-o-bot-4.html
Pepper	Softbank Robotics, Japan	TP, SA	https://www.ald.softbankrobotics.com/en/cool-robots/pepper

The Robot Report has listed⁴ manufacturers of “*robotic-augmented prosthetics*”. Control of a prosthetic arm using nerve signals is well under development⁵. US DARPA has had a “Revolutionizing Prosthetics” program⁶ active since 2006 and has now presented the results⁷.

Note that robotic gait therapy systems are also available and are used in Finland, e.g. as provided by Fysioline⁸.

Many different technologies and systems could be introduced to support elderly care. However, it would be a waste of effort to introduce something that is not accepted by all users and related interested groups. They all should get clear benefits. There are many examples of less successful technology pushes⁹, e.g. Rentschler et al. (2008) tested an *Assistive Mobility Device (AMD)*, i.e. a mechanical “rollator”, or wheeled walker¹⁰, against a robotic walker named *Guido*. Both devices

⁴ <https://www.therobotreport.com/news/advancements-and-commercial-uses-in-prosthetics>, 13th Dec., 2016

⁵ http://www3.imperial.ac.uk/newsandeventspggrp/imperialcollege/newssummary/news_6-2-2017-13-48-49, 17th April, 2017

⁶ <http://www.jhuapl.edu/prosthetics>, 21st April, 2017

⁷ <http://www.jhuapl.edu/prosthetics/program/news.asp>, 21st April, 2017

⁸ <http://www.fysioline.fi/collections/hocoma-lokomat>,

<http://www.theseus.fi/handle/10024/100384>, 22nd Aug., 2016

⁹ https://en.wikipedia.org/wiki/Technology_push, 22nd Aug., 2016

¹⁰ [https://en.wikipedia.org/wiki/Walker_\(mobility\)](https://en.wikipedia.org/wiki/Walker_(mobility)), 24th Aug., 2016

&

provided similar results and benefits to the users, but robot walkers are several orders of magnitude costlier. Nice ones will, however, evolve, such as LEA, developed¹¹ by Robot Care Systems in the SILVER¹² project.

Beedholm et al. (2016) analysed the introduction of a “robot bathtub” in a Danish elderly care centre. The closed bathtub is actually a semi-automated washer, into which nurses help persons in undressing and entering in a lying position on wheels. Watering, soap wash and rinse cycles operate semi-automatically with a nurse at the control panel. Cleaning and disinfection of the empty bath cabin are automated. There are photos of the bathtub in the web¹³, but it seems to have vanished from the market, although 1 000 units are claimed to be in use.

Beedholm et al. (2016) demonstrated how important it is to take all interest groups into account in the acquisition process of the robot. Especially the nurses that assist persons to enter the washer cabin and who did the washing before the “robot system” was acquired were very important. These outlines clarify the essence of correct introduction:

“... it was clear from the beginning that the robot bathtub would not be labor-saving.”

“... the nursing staff was led to identify the problem ‘independently’ based on the premise that they needed a robot bathtub.”

“... one of the users, who, in her wheelchair, cut the cord”

“... robot bathtub as a solution to increase the users’ experience of well-being and integrity and to relieve the labor of nursing staff.”

“... it’s different from someone washing you.”

Technology is not a single key to successful care robot applications. Robotic systems and their usage including supporting systems must be designed in a human-oriented manner. Development is typically made step by step from the concept of operation to requirements, detailed design, implementation, sub-system integration, testing and verification, system verification and finally to operation and maintenance, i.e. according to the so-called V-model¹⁴ (see e.g. the Figure 2 by Slashme, 2005¹⁵). The Dependable Systems Research Group of AIST¹⁶ has extended the model to a “Nursing-care robot development V model¹⁷”.

¹¹ <https://vimeo.com/171714584>, 2nd Sept., 2016

¹² <http://www.silverpcp.eu/>, 2nd Sept., 2016

¹³ www.roboregion.eu/filer/robin-results, (pdf), 1st Sept., 2016

¹⁴ <https://en.wikipedia.org/wiki/V-Model>, 7th April, 2017

¹⁵ https://commons.wikimedia.org/wiki/File:Systems_Engineering_Process_II.svg, 6th June, 2017

¹⁶ http://www.aist.go.jp/index_en.html, , 1st Sept., 2016.

¹⁷ https://unit.aist.go.jp/rirc/en/team/dependable_systems.html, 1st Sept., 2016.

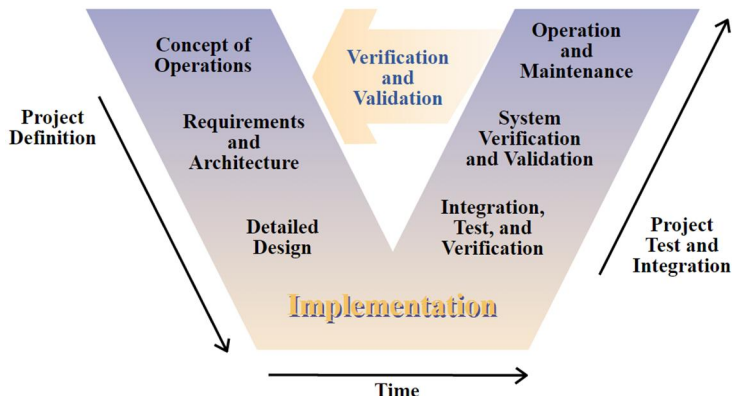


Figure 2. Development according to a V-model version (Slashme, 2005)

SoftBank¹⁸ has apparently realised how robotics can be adapted to fruitful business. The main idea is to provide tools for application developers, i.e. software¹⁹ (SDK) and hardware²⁰ platforms and to allow them to sell their applications while also leveraging the platforms. Softbank has formed powerful alliances to fund the platform development, e.g. with²¹ Alibaba and Foxconn. Note that Pepper and her mates (Nao and Romeo) therefore have considerable development resources behind them. The research community has claimed that the “Pepper platform software” is rather closed and it is difficult to realise new services with the robots (see e.g. Isoaho (2016) for an analysis of Nao software development). Software is actually the key – and the opportunity as Isoaho (2016) reveals:

“A Belgian company made a new, very intuitive UI [User Interface] in Nao and renamed it as Zora. Now they are selling it for 20 000€, whereas the Nao price is 6 000€.”

Softbank robots are hitherto not good at grasping objects. There will obviously be new releases at a later date.

Success of Nao generates naturally competition. Ubtech²² is selling their Alpha²³ robot to service the whole family. Combination of Ubtech robots and Amazon’s Alexa will give also spoken reminders²⁴.

¹⁸ <http://www.softbank.jp/en/corp/>, 11th Nov., 2016

¹⁹ <https://developer.softbankrobotics.com/>, 11th Nov., 2016

²⁰ <https://www.ald.softbankrobotics.com/en/cool-robots/buying-a-robot>, 11th Nov., 2016

²¹ http://www.softbank.jp/en/corp/news/press/sb/2015/20150618_01/ & <https://www.therobotreport.com/news/foxconn-and-alibaba-invest-in-softbank-robotic-holdings>, 11th Nov., 2016

²² <http://www.ubtrobot.com/index.html>, 5th June, 2017

²³ <http://www.ubtrobot.com/product/detail1.html>, 5th June, 2017

²⁴ <https://www.ubtrobot.com/news/detail196.html> & <https://www.youtube.com/watch?v=E1AtfHm4hf8>, 5th June, 2017

2. Digitalisation as an enabler

If it is desired to extend the period elderly people can live at home, it is necessary to utilise all means in a balanced manner. Among the means are:

- home automation i.e. “Smart homes²⁵”
- telemedicine²⁶
- telepresence²⁷ e.g. with relatives, external services and medical personnel
- eHealth²⁸
- mHealth²⁹
- Auxiliary services such as security surveillance (e.g. by Knightscope³⁰ robots)

Web-connected units e.g. tablets, smartphones or “tablet robots” are very multifunctional tools in elderly care. The internet is actually a gateway, which links equipment and services together. The following services could be available with web-connected units at home, on travel and during visits to health care facilities:

- telepresence, e.g. video calls to relatives, friends, healthcare personnel and interpreters
- hearing aid equipment access and control
- online assistance to blind persons or persons with severe hearing problems
- wearable measurement data can be sent to central supervision

²⁵ https://en.wikipedia.org/wiki/Home_automation, 5th Sept., 2016

²⁶ <https://en.wikipedia.org/wiki/Telemedicine>, 5th Sept., 2016

²⁷ <https://en.wikipedia.org/wiki/Telepresence>, 5th Sept., 2016

²⁸ <https://en.wikipedia.org/wiki/EHealth>, 5th Sept., 2016

²⁹ <https://en.wikipedia.org/wiki/MHealth>, 5th Sept., 2016

³⁰ <http://knightscope.com>, 5th Sept., 2016

- robot motion commands, medication automation commands and reminders or commands to smart home equipment can be given from a distance
- individual health care information may be accessed or personal health care personnel called in emergency cases
- automated or button activated emergency calls

McWilliams of BCC Research (2016B) estimated that telepresence robots called here “tablet robots” had a 4.5 million USD market in 2016, but that the market will grow to 200 M USD by 2026, i.e. 46% annually.

It is understandable that families who take care of their elderly parents would like use telepresence robots to discuss with and check the status of the parents occasionally during the day, when the younger inhabitants are absent. It is estimated that sufficient mobile tablet robots i.e. combination of local telepresence interface and a mobile robot moving it will be available on the market from 2018 with monthly costs in the range of 100 EUR.

When and if all is integrated together in an automated system, then there will be “integration benefits” that are not easily estimated. The reaction speed will be typically clearly improved, because all data is immediately accessible and available.

Alwan et al. (2006) concluded on the need for fall detectors:

*“Falls are ... the second leading cause of unintentional-injury death for people of all ages and the **leading cause of death for elders 79 years and older.** ...the medical outcome of a fall is largely dependent upon the response and rescue time.”*

Falls caused 79% of all *Traumatic brain injury* (TBI) cases³¹ to persons older than 64 years in the United States in 2013.

³¹ https://www.cdc.gov/traumaticbraininjury/get_the_facts.html, 1st June, 2017

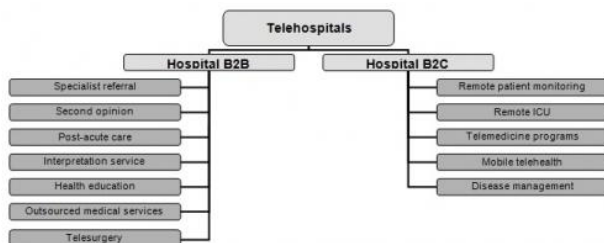


Figure 3 Telehospital B2B and B2C services (McWilliams, 2016) Source: BCC Research, Copyrighted Material, All rights reserved

Accelerometers as wearable devices are typically used to detect falling, see e.g. the review of Chaudhuri et al. (2014). Falling or colliding with the floor can often be estimated in advance. This would lead to time to activate dedicated safety belts e.g. by ActiveProtective³². If Kinect³³ or a similar sensor is used, it can also be used for fall detection. See e.g. Mastorakis & Makris (2014) and Enacer³⁴. The Finnish MariCare has floor based solutions³⁵ for fall detection.

2.1 Smart homes

We should all have smart homes, but they would give the most effective service to elderly and disabled people³⁶. For example, the following services would clearly extend and enable independent living at home:

- Automatic lights and illumination
- Gesture interface to lights, curtains and shades
- Ventilation control based on CO₂ measurements
- Temperature control
- Automatic doors
- Automatic call of elevators
- Central locking and power-off of equipment
- Central reminder visualisation or audio broadcasting at home
- Robotic tablet as a user interface with audio activation and feedback.

³² <http://activeprotective.com>, 26th Sept., 2016

³³ <https://en.wikipedia.org/wiki/Kinect>, 25th Aug., 2016

³⁴ <https://www.enacer.com/heimdall>, 16th Jan., 2017

³⁵ <http://www.maricare.com/elsi/index.php/en/solutions/nursing-homes>, 27th Oct., 2016

³⁶ https://en.wikipedia.org/wiki/Home_automation_for_the_elderly_and_disabled, 5th Sept., 2016

In other words, the home of an elderly person should be integrated into one automation system, which supports operation control and/or supervision from external systems e.g. supervised by nurses or relatives or from the tablet of the inhabitant or from a local control system “preprogrammed” by the inhabitant or a learning system based on previous activities.

There are actually supervision systems designed to follow the activities of elderly persons at home during normal living e.g. Healthsense³⁷ and QuietCare³⁸. However, static sensors can be replaced with wearable activity sensors. They can be utilised also during travel and outside the home and also to measure vital signals. Combinations of static sensors, sensors at home and wearable sensors may turn out to be the most reliable and to give the least false alarms.

2.2 Mobile computing

As we all hope for simplicity when using computers, special dashboards for elderly persons have been developed. GrandCare³⁹ is an example. Such an interface has to be available for different equipment, e.g. phone, tablet, PC, and for persons with viewing, hearing and motion disabilities.

Society Solutions⁴⁰ has a more integrated approach. They have GoLiveWear, which is a wearable “*movement tracker, fall detector and emergency button in one*” connected to a smartphone application, that in addition to medication reminders “*includes activity monitoring, fall detection, fall risk analysis, geo fencing, informal caregiver integration and remote management*”. A tablet interface is also available.

Enacer has combined medication reminders and telepresence with a moving tablet (RITA⁴¹) to assist elderly persons at home.

Smartphones and tablets are becoming essential and necessary in everyday life. They are becoming gateways for a set of ubiquitous computing and wearable devices. Retired people have already noticed the necessity to use smartphones and tablets, and continue using their computers during active periods of their retirement period. When using computers becomes difficult as we become older, we all wish to use those tools and portals we have noticed simple, effective and helpful. Learning new ones becomes difficult.

Service lists provided by portals should be short and should contain prices, as price is often an issue. As poor comparability is a marketing method, portal service providers should analyse and compare the offers to some extent. Elderly care is strongly subsidised in Finland and in Europe, and therefore the subsidised price should also be calculated. A link to instructions on how to arrange the subsidy is also a benefit.

³⁷ <http://healthsense.com/>, 21st April, 2017

³⁸ <https://www.careinnovations.com/quietcare/>, 21st April, 2017

³⁹ <https://www.grandcare.com/programs/pace-program>, 12th Dec., 2016

⁴⁰ <http://www.gocietysolutions.com/>, 13th Dec., 2016

⁴¹ <https://www.enacer.com/rita>, 16th Feb., 2017

“Life Alert⁴²” shows that the simplest interface, i.e. an emergency button, can be utilised to provide complex nation-wide services based on information collected in advance and emergency dispatching centres.

The examples above show that the marketing of support for elderly persons and the networks of assisting persons is a complex area and at the same time a huge potential market.

2.3 Telemedicine

Khosravi and Ghapanchi (2016) analysed assisting systems to help “*older adults*”. Their typical problems are “(1) *dependent living*, (2) *fall risk*, (3) *chronic disease*, (4) *dementia*, (5) *social isolation*, (6) *depression*, (7) *poor wellbeing*, and (8) *poor medication management*”. These factors are taken care of by systems utilizing ICT, robots, telemedicine, sensors, medication management and video games.

According to the analysis of Isoaho (2016), the first care robot applications should have the technological maturity to tackle the following problems:

- exercise training
- loneliness
- cognitive training
- reminding

Khosravi and Ghapanchi (2016) reported telemedicine to be a very effective tool to help older adults:

*“... telemedicine can be used as a cost-effective way to reduce unnecessary hospitalisation and to ensure that patients receive urgent care in a timely fashion. ... Telemedicine is the only technology applied to assist seniors with chronic disease which resulted in significant changes in the participants’ lives, from improvement in health conditions to reductions in hospital readmissions. ... the use of assistive technologies not only **elevates the quality** of the senior individual’s **life**, but **also** has a positive impact on the healthcare system by **reducing costs, readmissions and the length of hospital stays.**”*

McWilliams (2016) defined telemedicine as:

“use of telecommunications technology to deliver medical information or services to patients or other users at a distance from the provider”.

⁴² <http://www.lifealert.com>, 21st April, 2017

Additionally, the following concepts were clarified (McWilliams, 2016):

- telehospital: “*telemedicine services that are provided within or between hospitals, clinics or other healthcare providers, such as referrals, second opinions and education*”
- telehome: “*telemedicine services provided to the outpatient*” i.e. patients or recovering persons outside the hospital

Telemedicine will be an essential part of home care. McWilliams (2016) estimated that markets for telehospitals and telehomes (Figure 4) and related services (Figure 5) will grow rapidly, i.e. about 20% annually towards 2021. The Telehome market will be about 55 billion USD in 2021. MDLIVE⁴³ and Seniors Wireless⁴⁴ are examples. All key players have or are planning related businesses e.g. Verizon⁴⁵.

Telemedicine can also be used to reduce costs or even to activate and enable otherwise impossible care as has been done in Zambia⁴⁶ and Bolivia⁴⁷.

Frost & Sullivan (N.N., 2016) estimated that “*The medical wearables market will reach \$6 billion in 2016*”. Wadhwa (2016) of BCC Research has estimated the global market of “*patient monitoring device end users – home-based users*” to 5.4 billion USD in 2015 and estimated it to grow to 9.2 billion USD in 2020 (CAGR of 11.2%). The largest CAGR 14.8% will be in Asia-Pacific, see Figure 6 below.

It is possible to supervise thousands or even millions of persons in one system in a standardised manner. The ROSE project has visualised this concept as in Figure 7 below. When there is a large number of patient records in the system, it is possible to teach diagnostics to the system using machine learning⁴⁸ and artificial intelligence⁴⁹ (AI) methods. In other words, the system may predict what will happen next with the patient at hand using the experience obtained from previous patients.

Segment	2015	2016	2021	CAGR% 2016-2021
Telehospitals/clinics	11,066.0	12,489.6	22,006.5	12.0
Telehome	9,034.0	11,288.7	33,087.6	24.0
Total*	20,100.0	23,778.3	55,094.0	18.3

Figure 4 Global telehome and telehospital/clinic markets (M USD) (McWilliams, 2016) Source: BCC Research, Copyrighted Material, All rights reserved

⁴³ <https://welcome.mdlive.com>, 3rd Nov., 2016

⁴⁴ <https://www.seniorswireless.com/wellness>, 3rd Nov., 2016

⁴⁵ <http://www.verizonenterprise.com/industry/healthcare/>, 3rd Nov., 2016

⁴⁶ <http://www.virtualdoctors.org/our-programmes/#programmes>, 3rd Nov., 2016

⁴⁷ <http://ehealthreporter.com/en/noticia/legacy-3197/>, 3rd Nov., 2016

⁴⁸ https://en.wikipedia.org/wiki/Machine_learning, 16th Feb., 2017

⁴⁹ E.g. https://en.wikipedia.org/wiki/Artificial_intelligence & <https://www.linkedin.com/pulse/artificial-intelligence-law-state-play-2016-part-1-michael-mills>, 16th Feb., 2017

Segment	2015	2016	2021	CAGR% 2016-2021
Telehospital/clinic	8,231.2	9,359.5	17,050.2	12.7
Telehome	3,515.6	4,465.3	14,146.2	25.9
Total	11,746.8	13,824.8	31,196.4	17.7

Figure 5 Global telemedicine service market, (M USD) (McWilliams, 2016) Source: BCC Research, Copyrighted Material, All rights reserved

MedStar⁵⁰ of Cybernet⁵¹ is an example of a wearable health monitoring system with an exhaustive list of measurements and services (17 items) to monitor elderly persons at home. ViSi Mobile⁵² of Sotera Wireless measures the most indicative vital signals in order to estimate the status of hospital patients on-line.

Region	2014	2015	2020	CAGR% 2015-2020
North America	2,176.7	2,419.3	4,100.8	11.1
Europe	1,617.4	1,756.3	2,732.7	9.2
Asia-Pacific	771.9	861.1	1,715.2	14.8
ROW	344.7	378.0	677.0	12.4
Total	4,910.7	5,414.7	9,225.7	11.2

Figure 6 Global patient monitoring device end users – home-based user market, (M USD) (Wadhwa, 2016) Source: BCC Research, Copyrighted Material, All rights reserved

Figure 7 visualises a wearable vest with several appliances and a battery system. Wearable equipment may also perform medical operations autonomously, e.g. the LifeVest⁵³ of ZOLL.

Commercial sports class wearable systems may make a large number of measurements from a wrist-attached sensing system.

There are even globally considerable restrictions and requirements for medical devices. In general:

- they must be tested according to clear procedures, e.g. “clinical trials⁵⁴”
- instructions and descriptions must be clear and unambiguous
- marketing material must not be misleading.

⁵⁰

http://www.cybernet.com/index.php?option=com_content&view=article&id=249:medstar&catid=9&Itemid=589, 5th Dec., 2016

⁵¹ <http://www.cybernet.com/index.php/about-cybernet/history-and-vision>, 11th Nov., 2016

⁵² <http://www.soterawireless.com/visi-mobile>, 21st March, 2017

⁵³ <https://lifevest.zoll.com>, 21st March, 2017

⁵⁴ https://en.wikipedia.org/wiki/Clinical_trial, 30th Nov., 2016

All equipment, including sports and recreational wearable appliances, must fulfil several requirements and standards, e.g. “CE marking⁵⁵”. Note that CE marking is made by the manufacturer in Europe, but in USA the FDA⁵⁶ checks conformity and approves all medical equipment. Wearable devices that measure body signals in a clearly medical context should in addition meet the medical test and conformity requirements. In Europe the most relevant of these is the *Council Directive 93/42/EEC⁵⁷ concerning medical devices*. The related law in Finnish is the “*Laki terveydenhuollon laitteista ja tarvikkeista⁵⁸ (629/2010)*”.

The concepts in Figure 7 and Figure 23 are for medical use. However, wearable measurement equipment for sports and recreational use could be used for medical purposes in order to measure the condition and activity levels of people – especially those in elderly care. They could give an indication of whether additional help, e.g. a primary care ambulance, should be sent, or whether further medical tests are necessary, or that there is most probably no need for additional medical procedures despite the fact that an ambulance has been requested.

The wearable measurement equipment for sports and recreational use are typically manufactured in such large numbers that their manufacturing costs compared to medical devices with similar functionality are much lower. Typical sports measurements such as location, pace, steps, heart rate, sleep quality and sleep time would clearly be valuable information in the health care of elderly people if they could be monitored and supervised from a distance and during travel. Combining these factors with medical grade measurements such as blood pressure, INR⁵⁹, glucose and body temperature would increase the medical value of both measurement groups. If several measurements made by off-the-shelf-equipment from the market are used in parallel, their energy storage and charging systems may need some redevelopment or auxiliary units. There is actually a good business

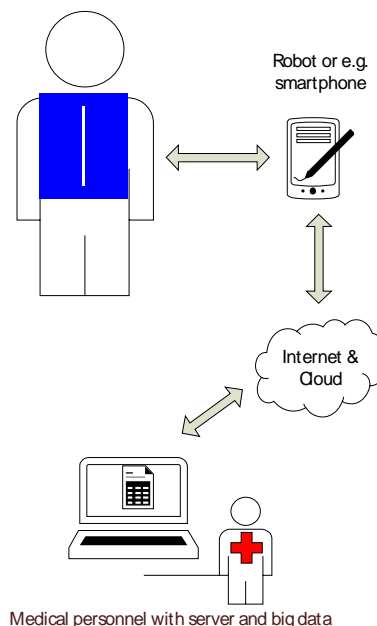


Figure 7 Wearable measurements supervised from medical centre

⁵⁵ https://en.wikipedia.org/wiki/CE_marking, 30th Nov., 2016

⁵⁶ <http://www.fda.gov>, 7th Dec., 2016

⁵⁷ <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:1993L0042:20071011:en:PDF>, 30th Nov., 2016

⁵⁸ <http://www.finlex.fi/fi/laki/alkup/2010/20100629>, 30th Nov., 2016

⁵⁹ https://en.wikipedia.org/wiki/Prothrombin_time#International_normalized_ratio, 1st Dec., 2016

opportunity for any company which would make an integrated “multi-instrument” measuring several medical and activity signals with selectable options.

Minna Kymäläinen of Valvira⁶⁰ checks that rules on medical equipment are followed in Finland. She clarified in November 2016 that:

- Purpose and usage of equipment are often described insufficiently. This leads in many cases to insufficient testing and inadequate risk analysis. See ISO 14971⁶¹ for advice.
- If equipment has a very narrow field of usage and purpose in the description, then the medical tests are also low in both efforts and costs.
- It is nowadays also possible to test sports equipment in medical use. A notification⁶² with descriptions should be sent to Valvira on the tests. The related decree⁶³ is available in Finnish and in Swedish.
- Additional and potential features and capabilities are often described too broadly. If described, they should be tested and their functionality and safety should be demonstrated before use.

As privacy is a concern for many people, the system should be applied **only on a voluntarily basis** and should utilise the following principles:

- wearable measurement data with identity should be accessible only to medical personnel or named relatives of each person measured
- encrypted communication (of course)
- a face figure of the caller of incoming telepresence calls is shown in addition to the name, and a medical logo in the case of medical personnel.

Applying the sensing system to voluntary persons only is wise, because the user benefits should be clear, spreading from mouth to mouth. When this process starts, the demand will increase rapidly and installation of the systems will become a bottleneck.

The following sections outline additional examples of health-related wearable systems.

Orpyx has developed insoles⁶⁴ to shoes that activate the wearer to move periodically in order to sustain motion capability in the case of restricted blood circulation.

Omron has several wearable blood pressure monitoring systems⁶⁵ and the possibility to transmit the results further via a smartphone.

⁶⁰ <http://www.valvira.fi/web/en/front-page>, 30th Nov., 2016

⁶¹ https://en.wikipedia.org/wiki/ISO_14971, 7th Dec., 2016

⁶² <https://lomake.fi/forms/pdf/Valvira/val73/en>, 19th April, 2017

⁶³ <https://www.finlex.fi/fi/viranomaiset/normi/562001/39644>, 19th April, 2017

⁶⁴ <https://orpyx.com/pages/surrosense-rx>, 21st March, 2016

⁶⁵ <https://omronhealthcare.com/blood-pressure/blood-pressure-monitor-product-selector>, 19th April, 2017

The Belgian company Cefaly Technology has developed a wearable anti-migraine device called Cefaly⁶⁶. More than 200 000 units are claimed to be in use.

SENSUS⁶⁷, Quell⁶⁸ and AcuKnee⁶⁹ appear to block pain by extra electrical nerve signals, although the explanations provided by the brands are not very scientific. So-called “*Transcutaneous electrical nerve stimulation*”⁷⁰ (*TENS*) is utilised. LifeMonitor⁷¹ of Equivital monitors e.g. persons engaged in dangerous work.

About 400 million people have diabetes⁷². The disease is related to unsuitable glucose levels in the blood. Our brains require a rather constant level of glucose in blood. If the level is too high, insulin is generated automatically in order to reduce the concentration. People suffering from diabetes cannot control their blood glucose level automatically. Instead, they measure blood glucose levels by technical means and inject artificial insulin to control the level. Currently there are wearable glucose measurement systems, e.g. FreeStyle Libre⁷³, Dexcom G4⁷⁴ and CONTOUR NEXT LINK⁷⁵. These can send measurement results to a human interface (e.g. smartphone) but also to automated insulin pumps e.g. V-Go of Valeritas⁷⁶. For example the “MiniMed Paradigm Revel”⁷⁷ and the combination⁷⁸ of MiniMed 530G and Elite sensor of Medtronic and the Accu-Chek Combo system⁷⁹ of Roche both measure glucose levels and when necessary pump insulin. Hitherto the glucose sensors on the market have had miniature needles to obtain fluid samples, but a non-invasive glucose monitor is under development e.g. by MediWise⁸⁰, Verily⁸¹ and Dia-Vit⁸². Footfalls & Heartbeats is heading towards the detection of diabetic ulcers⁸³ with smart textiles.

⁶⁶ <http://www.cefaly.com>, 21st March, 2016

⁶⁷ <http://www.sensusrx.com/>, 28th March, 2017

⁶⁸ <https://www.quellrelief.com/how-quell-works>, 28th March, 2017

⁶⁹ <https://www.acuknee.com/electrotherapy/>, 28th March, 2017

⁷⁰ https://en.wikipedia.org/wiki/Transcutaneous_electrical_nerve_stimulation, 19th April, 2017

⁷¹ <http://www.equivital.co.uk/products/industrial>, 21st March, 2016

⁷² <http://www.who.int/mediacentre/factsheets/fs312/en/>, 20th April, 2017

⁷³ <http://www.freestylelibrepro.us/blood-glucose-monitoring-device.html>, 31st March, 2017

⁷⁴ <http://www.dexcom.com/dexcom-share>, 20th April, 2017

⁷⁵ <http://www.medtronicdiabetes.com/products/contour-glucose-meter>, 31st March, 2017

⁷⁶ <https://www.valeritas.com/Home/default.aspx>,

⁷⁷ <http://www.medtronicdiabetes.com/products/minimed-revel-insulin-pump>, 31st March, 2017

⁷⁸ <https://www.medtronicdiabetes.com/products/minimed-530g-diabetes-system-with-enlite>, 2nd April, 2017

⁷⁹ <https://www.accu-chek.com/insulin-pumps-integrated-systems/combo-system/support>, 19th April, 2017

⁸⁰ <http://www.gluco-wise.com>, 31st March, 2017

⁸¹ <https://verily.com/projects/sensors/smart-lens-program/> &
<https://verily.com/projects/sensors/miniaturized-gcm/>, 27th April, 2017

⁸² <http://dia-vit.com/>, 31st March, 2017

⁸³ <http://www.footfallsandheartbeats.com/index.cfm/discovery/fabric-applications>, 3rd April, 2017

Other examples of wearable equipment are listed below. There are also dedicated medical wearables that are mentioned in order to detect certain symptoms, i.e. a certain disease:

- Cardiovascular disease (CVD⁸⁴), developed e.g. by Oresko et.al. (2010) of the Univ. of Pittsburgh
- Chronic obstructive pulmonary disease (COPD⁸⁵) often leads to the use of wearable equipment to provide supplementary oxygen
- Oxygen content in blood e.g. by Omron⁸⁶
- Alert buttons e.g. Biisafe⁸⁷ and Life Alert⁴²
- Asthma detection⁸⁸ by HCO
- INR⁸⁹ monitoring to adjust coagulation characteristics of blood e.g. with Marevan i.e. Warfarin⁹⁰ e.g. by Alere⁹¹ and Roche⁹²

VTT researchers Ermes et al. (2008) recognised the needs and benefits of automated activity tracking. It is possible to monitor remotely heart beat rate, resting pulse, depth of sleep, motion state (walking, running, cycling or stationary) and number of daily steps with 100 EUR price range activity trackers. This is not medical information, but provides some indication of the motion capability of the person and a history of measurements gives an indication that the person is in a normal state.

Recent wearable measurement projects have been carried out with large numbers of wearable sensors e.g. by Verily⁹³, Samsung⁹⁴ and Stanford⁹⁵. Stanford outlined:

*“that, given a baseline range of values for each person, it is possible to monitor deviations from normal and associate those deviations with environmental conditions, illness or other factors that affect health. **Distinctive patterns** of deviation from normal seem to **correlate with particular health problems**. ... goal is to anticipate and*

⁸⁴ https://en.wikipedia.org/wiki/Cardiovascular_disease, 24th April, 2017

⁸⁵ https://en.wikipedia.org/wiki/Chronic_obstructive_pulmonary_disease, 24th April, 2017

⁸⁶ <https://omronhealthcare.com/blood-pressure/zero/>, 24th April, 2017

⁸⁷ <https://www.biisafe.com/biisafe-portal/>, 24th April, 2017

⁸⁸ <http://healthcareoriginals.com/solution/>, 26th April, 2017

⁸⁹ https://en.wikipedia.org/wiki/Prothrombin_time, 26th April, 2017

⁹⁰ <https://en.wikipedia.org/wiki/Warfarin>, 26th April, 2017

⁹¹ <http://www.alere.com/en/home/product-details/inratio-pt-inr-monitoring-systems-us.html?c=US>, 26th April, 2017

⁹² http://www.coagucheck.com/coagucheck_patient/landing, 26th April, 2017

⁹³ <https://www.technologyreview.com/s/604198/googles-verily-unveils-a-health-watch-for-research>, 27th April, 2017

⁹⁴ <https://www.simband.io/documentation/sensor-module-documentation/simsense>, 27th April, 2017

⁹⁵ <https://med.stanford.edu/news/all-news/2017/01/wearable-sensors-can-tell-when-you-are-getting-sick.html>, 24th April, 2017

prevent disease in the healthy and to precisely diagnose and treat disease in the ill. ... data revealed four separate bouts of illness and inflammation, including the Lyme disease infection”

There are many software providers who carry out health analysis using data which wearables have measured. VivaMetrica claims⁹⁶ to have created tools to “*predict risk for chronic diseases and mortality*”. MedeAnalytics⁹⁷ has a Big Data approach to all medical data. They claim to have “*Data on over 21 billion episodic accounts and 30 million patients*”. Talend provides⁹⁸ software “*to determine when is the appropriate time for patients to repeat assessments*”.

Many services can be built around wearable measurements. For example, the Heart Health program⁹⁹ of Philips “*comprises a 24-week program ... helping to improve behaviours and learn new skills, with the last 8 weeks assisting in sustaining the new healthy habits*” including the use of Philips wearables. Apple has a HealthKit¹⁰⁰ platform for developing cooperating “*health and fitness apps*”.

Based on the observations and trends presented above and in this document, it is straightforward to propose, according to the concept in the Figure 7, that:

- A wearable system with a set of about 10 sensors measuring vital information and a central battery power, communication and charging sub-system could be developed for elderly care needs.
- All voluntary persons over the age of e.g. 80 years in Finland could be equipped with the wearable system and connected to central medical supervision.

It is assumed that there is a considerable global need for such systems and related software. It is also assumed that similar systems are already under development.

⁹⁶ <http://vivametrica.com/>, 26th April, 2017

⁹⁷ <http://medeanalytics.com/why-medeanalytics>, 26th April, 2017

⁹⁸ <https://www.talend.com/customers/centerlight-healthcare/>, 26th April, 2017

⁹⁹ <http://www.ifa.philips.com/news/health-and-home/philips-heart-health-program>, 28th March, 2017

¹⁰⁰ <https://developer.apple.com/healthkit/>, 4th May, 2017

3. Evolving robot automation applications

Robot technology evolves gradually based on previous applications. Therefore, it is good to know how robots have evolved and will evolve in other application fields. This area is examined in this section.

Robots currently represent a market of about 26 billion USD according to BCC Research (Wilson, 2016), excluding prostheses and exoskeletons. The market estimates and predictions are shown in Figure 8 and Figure 9 below.

Robot User	2014	2015	2016	2021	CAGR% 2016-2021
Automotive manufacturing	5,881	6,012	6,173	6,526	1.1
Healthcare	4,058	4,190	4,347	5,621	5.3
Government – defense	2,385	2,481	2,601	3,369	5.3
Consumer products manufacturing	2,331	2,428	2,570	3,214	4.6
Electrical and electronics manufacturing	2,252	2,355	2,494	3,101	4.5
Aerospace manufacturing	1,769	1,801	1,849	2,193	3.5
Government – non-defense	1,074	1,109	1,159	1,646	7.3
Food processing	1,291	1,322	1,361	1,552	2.7
Pharmaceutical manufacturing	943	988	1,055	1,351	5.1
Education and research	512	532	561	694	4.3
Building maintenance	454	461	475	576	3.9
Households	305	311	332	413	4.5
Textile and clothing manufacturing	255	264	287	361	4.7
Agricultural	254	260	281	348	4.4
Construction	213	214	242	342	7.2
Chemical and fuel processing	159	161	181	229	4.8
Total	24,136	24,889	25,968	31,536	4.0

Figure 8 Estimated and predicted robot markets by user (M USD) (Wilson, 2016)
Source: BCC Research, Copyrighted Material, All rights reserved

Robot-Performed Application	2014	2015	2016	2021	CAGR% 2016-2021
Assembly	6,327	6,552	6,819	8,111	3.5
Surgery	3,498	3,609	3,720	4,790	5.2
Welding and soldering	2,975	3,026	3,101	2,985	-0.8
Painting, coating and gluing	2,720	2,806	2,922	3,401	3.1
Inspection and sample collection	1,410	1,464	1,543	2,098	6.3
Surveillance	1,365	1,404	1,448	1,835	4.9
Palletizing and packaging	904	930	999	1,264	4.8
Part cutting and forming	905	933	1,000	1,208	3.9
Hazardous materials disposal	819	846	884	1,199	6.3
Material handling	671	690	719	998	6.8
Dispensing	623	648	691	883	5.0
Laboratory bench assistance	457	477	514	646	4.7
Assisted transport	393	416	451	637	7.2
Exterior maintenance	395	402	418	514	4.2
Floor maintenance	307	312	323	393	4.0
Construction and demolition	125	127	144	215	8.3
Building security	129	132	140	190	6.3
Couriers and guides	56	57	66	87	5.7
Entertainment	57	58	66	82	4.4
Total	24,136	24,889	25,968	31,536	4.0

Figure 9 Estimated and predicted robot markets by robot application (M USD) (Wilson, 2016) Source: BCC Research, Copyrighted Material, All rights reserved

Frost & Sullivan has estimated the “nursing robot market” (N.N., 2015B) as in the Figure 11. The estimated global market size is 21.7 billion USD in 2025. This indicates an average annual growth of 41.6% from 2015 to 2025. A more recent estimate of Frost & Sullivan (N.N., 2016E) also includes automation as “Care Assistance and Automation Robots Market”, as robots are – and should be – sold as part of semi or fully automated systems to support elderly people. Much will be done in transportation both in care-related logistics and transporting persons with automated systems. See Figure 10 below.

The standard “Safety requirements for personal care robots¹⁰¹” (ISO 13482:2014) was established in 2014. This is a positive factor to intensify the introduction of new care robots.

Note that healthcare is already the second largest robot user market section (Figure 8), and only 30% smaller than the biggest robot market section, i.e.

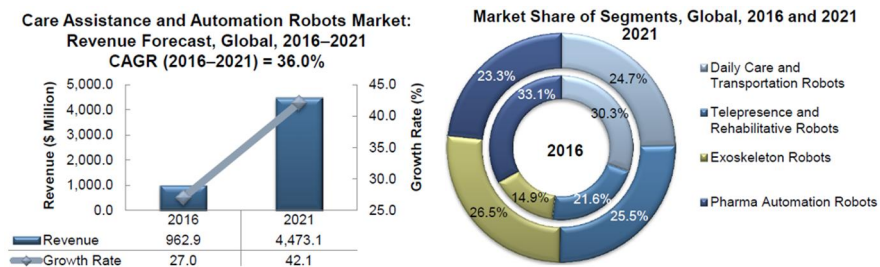


Figure 10 Estimates of the care assistance and automation robots market and related segments by Frost & Sullivan (N.N., 2016E)

¹⁰¹ http://www.iso.org/iso/catalogue_detail?csnumber=53820, 17th Feb., 2017

automotive manufacturing. This is actually due to the success of robots assisting and performing surgery, as Figure 9 indicates. Note also the concept of “assisted transport” in Figure 9. These are domestic service robots “primarily for the elderly” (Wilson, 2016). Demand on assisted transport is estimated to grow annually by 9.3% in “Europe Plus” and by 7.2% globally (Wilson, 2016).

As industrial robots can move their tools to any location and orientation within the workspace of the robot, industrial robots can be used in several medical tasks. The CyberKnife¹⁰² tumour treatment robot is an example, used e.g. in Kuopio¹⁰³. In addition to accurate repetition of tumour treatment tool positions, it reduces the radiation dose of medical personnel. X-ray robots are being developed e.g. by Siemens¹⁰⁴. Hair transplanting e.g. by ARTAS¹⁰⁵ is another example. Packing, palletising and logistics are other typical potential tasks for industrial class robot equipment.

BCC Research (McWilliams, 2016B) defined autonomous robots as follows: “can perform with a high degree of autonomy, making complex judgments and learning how to execute tasks on their own”. Figure 13 shows market size estimates and predictions for different types of autonomous robots. Note the high predicted growth for autonomous i.e. self-driving vehicles from 2021 onwards. These are widely predicted to be then safer than manually driven vehicles and therefore accepted in normal traffic. This means that planning of scalable elderly care transportation and logistics service applications should be designed and tested before 2021.

Nursing Robots Market: Revenue Forecast, Global, 2015, 2020, and 2025*

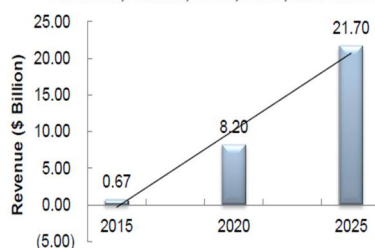


Figure 11 Estimated nursing robot market (N.N., 2015B)



Figure 12 Tumour treatment robot in Kuopio (E. Armstrong)

¹⁰² <http://www.cyberknife.com/cyberknife-overview/what-cyberknife.aspx>, 28th Nov., 2016

¹⁰³ <http://cyberknife.bonsait.fi> & <http://www.urn.fi/URN:NBN:fi:amk-2014112116209>, 28th Nov., 2016

¹⁰⁴ <https://www.healthcare.siemens.com/robotic-x-ray/twin-robotic-x-ray/multitom-rax>, 14th March, 2017

¹⁰⁵ <http://www.artashair.com/artas-experience/how-it-works/> & <http://restorationrobotics.com/>, 4th April, 2017

End Use	2015	2016	2021	CAGR% 2016-2021	2026	CAGR% 2021-2026
Cleaning robots	625.0	720.0	1,445.0	14.9	2,910.0	15.0
Robots for mining and energy production	393.0	432.2	643.3	8.3	1,356.6	16.1
Robots for scientific research	255.0	262.6	310.0	3.4	381.6	4.2
Military robots	106.3	125.7	262.5	15.9	2,353.3	55.1
Medical robots	3.2	4.5	30.0	46.1	200.0	46.1
Industrial robots	2.5	3.7	27.0	48.8	393.9	70.9
Agricultural robots	1.0	1.6	16.8	60.0	176.2	60.0
Self-driving vehicles	0.0	1.0	1.1	1.9	4,403.8	425.4
Total	1,386.0	1,551.3	2,735.7	12.0	12,175.4	34.8

Figure 13 Estimated and predicted autonomous robot markets by type of end-use (M USD) (McWilliams, 2016B) Source: BCC Research, Copyrighted Material, All rights reserved

Artificial intelligence⁴⁹ (AI) is currently in a state of rebirth and a hot research topic, and new robot applications are evolving continuously. Among such examples are:

- Cooking robots¹⁰⁶ learning by “watching” cooking videos
- Robots learning by trial and error¹⁰⁷

Note that when one robot has learned a task, it can easily transfer its experience to another robot.

3.1 Industrial robots

Industrial robots¹⁰⁸ can move their tools as required in their applications. The tool may occasionally or continuously:

- point in a desired direction (e.g. welding gun)
- have a desired orientation (e.g. assembly robot assembling complex parts in all directions).

¹⁰⁶ <http://www.techtimes.com/articles/30166/20150201/darpa-trains-robots-to-cook-by-watching-youtube-videos-why-its-significant.htm>, 28th April, 2017

¹⁰⁷ <http://www.kurzweilai.net/robots-master-skills-with-deep-learning-technique>, 28th April, 2017

¹⁰⁸ https://en.wikipedia.org/wiki/Industrial_robot, 8th March, 2017

Figure 14 shows the most common type of industrial robot in typical industrial robot duty. Industrial robots are usually of articulated type with all rotational joints as in Figure 14. Linear sliding motions are also used as in so-called gantry robots, e.g. by GÜDEL¹⁰⁹. Numerous combinations of linear and articulated joints have been tried in industrial robots. For example, SCARA i.e. Selective Compliance Assembly Robot Arm¹¹⁰ is flexible (compliant) in horizontal directions but rigid in the vertical direction. This is effective in mechanical assembly duties.

Robots can move their tools so that they interpolate the specified “tool tip point” in a linear manner and change the orientation of the tool with constant speed although it is an articulated robot. The continuous calculation of reference tool positions and orientations is called “linear interpolation”. Tool positions are converted further to reference joint angles with a calculation called “inverse kinematics”. Calculation of the tool tip position from joint angles is called “direct kinematics”.

Sales of industrial robots follow other factory technology investment trends. 254 000 industrial robots were delivered¹¹¹ in 2015 as estimated by the IFR, the International Federation of Robotics¹¹². 1.8 million industrial robots are estimated to have been operational globally at the end of 2016. About 13% annual growth is expected for the next few years.

There are an average of 69 industrial robots for 10 000 persons employed globally in the manufacturing industry¹¹¹. The Republic of Korea, Singapore, Japan, Germany and Sweden have the largest numbers, i.e. over 200 units. Finland had 126 in 2015.

About 300 new robots are installed in Finland annually. The corresponding number has been about 60 000 in China (40% of the global supply) during recent years.

Industrial robots as in Figure 14 can move their tools with 0.1 mm relative accuracy (resolution). Absolute accuracy is about ± 10 mm depending on the length of the tool.



Figure 14 Industrial robot by KUKA (Bachman, [2003](#))

¹⁰⁹ <http://www.gudel.com/products/robots/gantry-robot>, 8th March, 2017

¹¹⁰ <https://en.wikipedia.org/wiki/SCARA>, 10th March, 2017

¹¹¹ http://www.ifr.org/index.php?id=59&df=Presentation_market_overviewWorld_Robotics_29_9_2016_01.pdf, 10th March, 2017

¹¹² <http://www.ifr.org>, 13th March, 2017

Fast picking¹¹³ robots e.g. for chocolate applications were introduced in about the year 2000. Competition kept industrial robots rather similar to that shown in Figure 14 from the 1980s until about 2000. Then Yaskawa introduced a dual arm robot, SDA20D¹¹⁴. The German company KUKA¹¹⁵ introduced (versions of) LBR iiwa¹¹⁶. ABB followed with its dual arm YuMi¹¹⁷. This has the size of a human upper body, collision sensors in links (outer surfaces of arms) and a selection of grippers. It may be able to do the same simple assembly tasks that human beings do. Much effort has been made to guarantee that YuMi is not dangerous for the cooperating human. If the task has to be repeated, then it is useful to teach the YuMi. When programming of YuMi is automatic and occurs automatically when the product is designed, YuMi may find many applications. Hitherto, economic feasibility is the principal limitation.

ABB has a tradition to make accurate mechanical design to reach good accuracy for the tool of an ABB robot. This typically increases the price of the robot, although robot software is a far more expensive investment for the robot manufacturer than the mechanical design. This means that the production numbers of robot arms have to be large in order to justify the high software development costs.

If accuracy requirements are eased and plastic 3D printed parts are utilised in robot arms, it is possible to reduce the weight and price of the arms. The resulting flexibility of the arm can also be utilised in a positive manner especially in assembly tasks and e.g. in grinding. Universal Robots¹¹⁸ and Rethink Robotics¹¹⁹ are utilising these possibilities and appear to have had a successful start. Figure 15 below shows the dual arm Baxter robot of Rethink Robotics. Sawyer¹²⁰ and Intera¹²¹ are improved versions. The price of Baxter has been estimated¹²² to 22 000 USD. RightHand Robotics¹²³ utilises the Universal Robot arm for so-called “odd bin picking” in a nice manner. This illustrates how near to the picking of (almost) random objects the company has reached.

¹¹³ <http://new.abb.com/products/robotics/industrial-robots/irb-360> & <https://www.motoman.com/industrial-robots/mpp3s>, 14th March, 2017

¹¹⁴ <https://www.motoman.com/industrial-robots/sda20d>, 14th March, 2017

¹¹⁵ <https://en.wikipedia.org/wiki/KUKA>, 13th March, 2017

¹¹⁶ <https://www.kuka.com/en-de/products/robot-systems/industrial-robots/lbr-iiwa> & <https://www.kuka.com/en-us/technologies/human-robot-collaboration>, 13th March, 2017

¹¹⁷ <http://new.abb.com/products/robotics/industrial-robots/yumi>, 14th March, 2017

¹¹⁸ <https://www.universal-robots.com>, 14th March, 2017

¹¹⁹ <http://www.rethinkrobotics.com>, 14th March, 2017

¹²⁰ <http://www.rethinkrobotics.com/sawyer/>, 27th April, 2017

¹²¹ <http://www.rethinkrobotics.com/intera/>, 27th April, 2017

¹²² <http://www.dpaonthenet.net/article/131564/Get-ready-for-robotolution.aspx>, 17th April, 2017

¹²³ <https://www.righthandrobotics.com>, 6th April, 2017

Industrial robots can perform many repeatable tasks in industry that are also done in hospitals and care dormitories. Packing and palletising¹²⁴ of boxes are typical examples. Food boxes¹²⁵ can also be packed by robots. Robotic medication dispensing units e.g. by Aesynt¹²⁶ reduce related errors in hospitals.

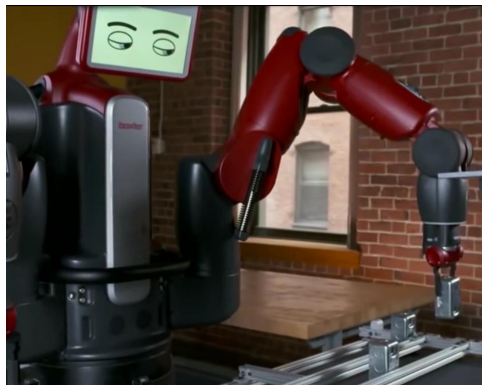


Figure 15 Baxter robot of Rethink Robotics (Salammbo31, [2014](#))

3.2 Autonomous vehicles

Autonomous vehicles, i.e. self-driving cars or driverless vehicles

drive typically under computer control. The necessary computers and sensing systems were prohibitively expensive during the first tests in the 1980s and automatic driving was legally impossible, so therefore hardly anybody considered autonomous passenger cars. Instead, there were possibilities to develop industrial autonomous vehicles for closed (i.e. fenced) areas. This is the reason for having two separated sections below.

Note that tele-operated vehicles do not have a driver on-board, but the human driver is at remote location and steers the vehicle from there.

3.2.1 Autonomous traffic vehicles

The first autonomous traffic vehicles capable of driving at highway speeds without drive actions were created¹²⁷ soon after 1985. See examples e.g. at the Navlab web pages¹²⁸. Since then, all automotive manufactures – and many other players – have developed prototypes of autonomous vehicles. Most of them drive more safely than manually driven vehicles.

For example, the following automotive brands have published prototypes or development plans on autonomous vehicles: Audi¹²⁹, BMW¹³⁰, Chrysler¹³¹,

¹²⁴ http://www.fanucrobotics.com/cmsmedia/videos/M-410iB%20Palletizing%20Boxes%20-%20General%20Electric_57_106.mp4, 17th march, 2017

¹²⁵ <https://www.universal-robots.com/applications/packaging-and-palletizing/> & <http://www.gereports.com/post/107898198705/rethink-robotics-is-freeing-next-gen-robots-from/>, 17th march, 2017

¹²⁶ <http://www.aesynt.com/central-pharmacy-products>, 4th April, 2017

¹²⁷ https://en.wikipedia.org/wiki/Autonomous_car, 21st Dec., 2016

¹²⁸ <http://www.cs.cmu.edu/afs/cs/project/alv/www/index.html>, 21st Dec., 2016

¹²⁹ <http://newatlas.com/audi-rs7-piloted-driving-concept-hockenheim/34324/>, 3rd Jan., 2017

¹³⁰ http://www.motorauthority.com/news/1094670_bmw-to-test-autonomous-cars-in-china, 3rd Jan., 2017

¹³¹ <http://newatlas.com/chrysler-autonomous-portal-concept-ces/47194/>, 4th Jan., 2017

Daimler¹³², Ford¹³³, Hyundai¹³⁴, Infiniti¹³⁵, KamAZ¹³⁶, Peterbilt¹³⁷, Renault/Nissan¹³⁸, SAIC¹³⁹, Scania¹⁴⁰, Tesla¹⁴¹, Volkswagen¹⁴² and Volvo¹⁴³. Navigant Research has ranked¹⁴⁴ related companies.

As the prospects for autonomous car business and evolving rideshare business, e.g. the autonomous shuttle taxi business are huge, many companies outside the automotive sector have also started autonomous vehicle design and production planning. Among these are Alphabet/Google/Waymo¹⁴⁵, Apple¹⁴⁶, Baidu¹⁴⁷, Continental¹⁴⁸, Mando¹⁴⁹, Navya¹⁵⁰, nuTonomy¹⁵¹, Robot Taxi¹⁵², Uber¹⁵³ and Zoox¹⁵⁴. The writer was able to list 55 automotive brands and newcomers from outside the automotive sector who had designed prototypes of autonomous road vehicles by January 2017.

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- ¹³² <https://www.fastcoexist.com/3047150/daimlers-new-self-driving-semi-drives-better-than-a-person-so-its-better-for-the-environment> & <http://www.4wheelsnews.com/auto/mercedes-benz-autonomous-cars-test-germany-36485.html>, 5th Jan., 2017
- ¹³³ <https://www.bloomberg.com/news/articles/2017-02-17/ford-s-doing-engineers-side-with-google-in-full-autonomy-push>, 2nd March, 2017
- ¹³⁴ http://www.koreatimes.co.kr/www/news/biz/2015/11/388_191560.html, 3rd Jan., 2017
- ¹³⁵ <http://www.freep.com/story/money/cars/mark-phelan/2016/12/30/infiniti-suv-concept-loaded-tech-debut-naias-detroit-auto-show/95965194/>, 5th Jan., 2017
- ¹³⁶ <https://sputniknews.com/russia/201506141023343802/>, 3rd Jan., 2017
- ¹³⁷ <http://www.peterbilt.com/about/media/2014/430/> & <http://dieseltalk.co.nz/news/self-driving-trucks-reality>, 5th Jan., 2017
- ¹³⁸ <http://autotalk.com.au/industry-news/autonomous-driving-features-coming-renault-nissan-alliance-carlos-ghosn>, 3rd Jan., 2017
- ¹³⁹ http://www.saicmotor.com/english/latest_news/saic_motor/38271.shtml, 3rd Jan., 2017
- ¹⁴⁰ <https://www.youtube.com/watch?v=sDGZPRJBeEQ>, 3rd Jan., 2017
- ¹⁴¹ <https://futurism.com/elon-musk-every-tesla-car-will-be-fully-autonomous-by-2017/>, 5th Jan., 2017
- ¹⁴² <http://newatlas.com/adpative-autonomous-driving-project/30695/>, 3rd Jan., 2017
- ¹⁴³ <http://gpsworld.com/volvo-presents-system-for-integrating-autonomous-cars-into-traffic>, 3rd Jan., 2017
- ¹⁴⁴ <http://www.navigantresearch.com/research/navigant-research-leaderboard-report-automated-driving>, 2nd June, 2017
- ¹⁴⁵ <https://www.wired.com/2016/12/googles-latest-self-driving-car-minivan/>, & <http://www.foxnews.com/auto/2017/01/08/waymo-says-self-driving-car-tech-is-getting-much-cheaper.html>, 9th Jan., 2017
- ¹⁴⁶ <http://www.drive.com.au/motor-news/spied-the-apple-car-20150609-ghk9y9>, 3rd Jan., 2017
- ¹⁴⁷ <https://www.bloomberg.com/news/articles/2016-01-24/baidu-enters-the-global-race-to-dominate-era-of-driverless-cars>, 4th Jan., 2017
- ¹⁴⁸ http://www.continental-automotive.com/www/automotive_de_en/themes/passenger_cars/ov_automated_driving_en/ & <http://newatlas.com/bmw-continental-autonomous-driving/26671/>, 4th Jan., 2017
- ¹⁴⁹ <http://pulsenews.co.kr/view.php?sc=30800019&year=2017&no=315715>, 6th June, 2017
- ¹⁵⁰ <http://navya.tech/?lang=en>, 5th Jan., 2017
- ¹⁵¹ <http://nutonomy.com/>, 5th Jan., 2017
- ¹⁵² https://robottaxi.com/en/?noredirect=en_US,
- ¹⁵³ <https://www.wired.com/2016/09/self-driving-autonomous-uber-pittsburgh/>, 5th Jan., 2017
- ¹⁵⁴ <https://www.therobotreport.com/news/zoox-raises-50-million-for-their-stealthy-silicon-valley-venture>, 5th Jan., 2017

Several computer/software, sensor and/or control companies are also actively developing hardware and software platforms to be applied in all kinds of autonomous and tele-operated cars. Among them are Drive.ai¹⁵⁵, Elektrobit¹⁵⁶, Bosch¹⁵⁷, CEVA¹⁵⁸, BlackBerry/QNX¹⁵⁹, Mobileye¹⁶⁰ (of Intel¹⁶¹), NVIDIA¹⁶², NXP¹⁶³, Pilot Automotive Labs¹⁶⁴, PolySync¹⁶⁵, Renesas¹⁶⁶, Siemens¹⁶⁷, Waymo¹⁴⁵, Zenuity/Volvo/Autoliv¹⁶⁸ and TomTom with Qualcomm¹⁶⁹. 25 companies developing platforms for autonomous vehicles were listed in January 2017. Mergers and acquisitions will occur frequently, as autonomous vehicles are now a hot topic and the related software is easy to apply to several types of vehicles. For example, GM acquired¹⁷⁰ Cruise and Uber Otto¹⁷¹ in 2016.

Autonomous driving will change traffic, transportation, logistics and travelling practices considerably. There are many evolving concepts – see e.g. those of Volkswagen¹⁷².

Dickmann et al. (2015) described a typical sensing system for an autonomous vehicle. It has “one stereo-vision system looking forward and one mono system for backward. Eight radar sensors covering 360° up to 200m”. Obviously, it also has inertial sensors, a few GPS, odometry (pulses from wheels) and steering angle sensors. The results of these sensing systems are fused together to estimate the location, direction and velocity of the vehicle in the map and relative to the nominal road lane. Some autonomous vehicles also have “laser radars” i.e. LIDARs¹⁷³ to generate a 3D model of the environment. It would be economically tempting to

¹⁵⁵ <https://www.drive.ai/>, 10th Jan., 2017

¹⁵⁶ <https://www.elektrobit.com/products/eb-assist/>, 5th Jan., 2017

¹⁵⁷ <http://www.techworld.com/news/personal-tech/bosch-creating-more-powerful-software-for-driverless-cars-3618847/>, 5th Jan., 2017

¹⁵⁸ <http://www.ceva-dsp.com/CEVA-XM6>, 5th Jan., 2017

¹⁵⁹ <http://www.marketwired.com/press-release/blackberry-creates-innovation-centre-for-connected-and-autonomous-vehicles-nasdaq-bbry-2184233.htm>, 9th Jan., 2017

¹⁶⁰ <http://ir.mobileye.com/investor-relations/press-releases/press-release-details/2016/The-Road-to-Full-Autonomous-Driving-Mobileye-and-STMicroelectronics-to-Develop-EyeQ5-System-on-Chip-Targeting-Sensor-Fusion-Central-Computer-for-Autonomous-Vehicles/>, 5th Jan., 2017

¹⁶¹ <https://newsroom.intel.com/news-releases/intel-acquire-mobileye/?wapkw=mobileye>, 17th March, 2017

¹⁶² <http://www.nvidia.com/object/drive-px.html>, 5th Jan., 2017

¹⁶³ <http://www.nxp.com/products/microcontrollers-and-processors/arm-processors/s32-arm-processors-microcontrollers/bluebox-autonomous-driving-platform-s32vls2-rdb:S32VLS2-RDB>, 5th Jan., 2017

¹⁶⁴ <http://www.pilotlab.co/>, 5th Jan., 2017

¹⁶⁵ <https://polysync.io/>, 5th Jan., 2017

¹⁶⁶ <https://www.renesas.com/en-sg/solutions/automotive/products/rcar-h3.html>, 5th Jan., 2017

¹⁶⁷ <http://www.projekt-race.de/en/home/index.php>, 5th Jan., 2017

¹⁶⁸ <http://www.automotiveworld.com/news-releases/volvo-cars-autoliv-announce-launch-zenuity/>, 9th Jan., 2017

¹⁶⁹ <https://www.qualcomm.com/news/releases/2017/02/26/qualcomm-drive-data-platform-powers-tomtoms-plans-crowdsource-high>, 15th March, 2017

¹⁷⁰ <http://fortune.com/cruise-automation-general-motors-driverless-cars/>, 10th Jan., 2017

¹⁷¹ <https://techcrunch.com/2016/09/27/uber-otto-freight-services-2017/>, 10th Jan., 2017

¹⁷² <http://www.caradvice.com.au/189135/volkswagen-trimaran-concept-kosin-voravattayagon/>,

¹⁷³ <https://en.wikipedia.org/wiki/Lidar>, 31st, Jan., 2017

reduce the number of sensing systems, but this would endanger the reliability of the self-driving system in difficult driving conditions. In any case, there are a number of evolving business opportunities in sensing systems for autonomous vehicles. Several types of cameras are used in autonomous vehicles and their automotive market is definitively increasing e.g. as a mirror replacement in manually driven cars.

As 3D maps of the road environment would simplify position estimation of the vehicle and therefore improve driving accuracy, there are also rapidly evolving business opportunities in 3D mapping of road environments. Each lamp post or tree trunk could be a beacon i.e. landmark that could be used to improve the accuracy of location estimation. Each beacon is used only partially to correct error drift in the location estimate. This means that one or a few missing beacons would not cause problems. Equally, unlisted new beacons are not accepted, as they are not in the 3D model. As autonomous vehicles are used in the future, they can update the 3D model “on-line” while driving and dedicated 3D modelling vehicles would no longer be needed.

Vehicles of Google and Here for 3D mapping and photographing roadside areas have been well reported in the news in recent years. Such data will be collected in the future by crowdsourcing i.e. passing semi or fully autonomous vehicles will collect the roadside data. TomTom and Qualcomm¹⁶⁹ are planning on just that.

Comma.ai¹⁷⁴ planned to sell their autopilot software as a smartphone app. Autonomous driving would have utilised the camera and calculation power of the smartphone and inertial sensors in the car and the smartphone. The combination was designed to act as an autopilot, i.e. highway driving assistant in compatible cars. The authorities¹⁷⁵ in California discontinued the operation, because the Comma.ai combination does not follow the prevailing and evolving regulations.. Consequently, comma.ai started to deliver the software and instructions free of charge as open software. Technology students have been able¹⁷⁶ to follow the instructions and improve their cars with self-driving capabilities. Liability issues are not solved, but so far there are no laws to prevent consumers from upgrading their cars by themselves. Any future accident may clarify these issues, in court and with delays.

¹⁷⁴ <http://comma.ai/>, 9th Jan., 2017

¹⁷⁵ <https://www.washingtonpost.com/news/the-switch/wp/2016/11/30/why-a-hacker-is-giving-away-a-special-code-that-turns-cars-into-self-driving-machines/>, 9th Jan., 2017

¹⁷⁶ <https://www.technologyreview.com/s/603637/how-a-college-kid-made-his-honda-civic-self-driving-for-700/>, 2nd March, 2017

The automotive brands have started to deliver autonomous driving functionality as partial functions to support driving. They are often grouped under the phrase “Advanced driver assistance systems¹⁷⁷” i.e. ADAS. They typically warn drivers of dangerous situations, e.g. unnoticed cars in blind spots, falling asleep, collision risk and driving off the road. Some functions also affect driving, e.g. “adaptive speed control” maintains a safe distance to the vehicle in front and emergency braking activates brake automatically in case of an estimated collision. SAE established a related standard¹⁷⁸ in 2014 (Figure 16). The present version was approved in 2016. Validity was discussed¹³³ early in 2017.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the <i>driving mode</i> -specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the <i>driving mode</i> -specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes
Automated driving system (“system”) monitors the driving environment						
3	Conditional Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to Intervene</i>	System	System	Human driver	Some driving modes
4	High Automation	the <i>driving mode</i> -specific performance by an automated driving system of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to Intervene</i>	System	System	System	Some driving modes
5	Full Automation	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	All driving modes

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Figure 16 Reference levels car automation (SAE J3016, 2016)

Strategy Analytics has published estimates on utilisation of ADAS functions¹⁷⁹ in the automotive sector. See these for ADAS details.

Tesla updated suddenly their software with an Autopilot¹⁸⁰ function in October 2015. Tesla Autopilot can make lane departure warnings and follow the car in front at a safe speed and distance, and also make the appropriate steering actions. New Tesla cars have hardware with which they could perform autonomous operations at SAE level 5, see Figure 16 above. Tesla warned drivers not to use the Autopilot to

¹⁷⁷ https://en.wikipedia.org/wiki/Advanced_driver_assistance_systems, 9th Jan., 2017

¹⁷⁸ http://standards.sae.org/j3016_201609/, 9th Jan., 2017

¹⁷⁹ <http://2pe5rtjld2w41m0dy17n5an1.wpengine.netdna-cdn.com/wp-content/uploads/2016/10/Strategy-Analytics-From-ADAS-to-Autonomous.pdf>, 10th Jan., 2017

¹⁸⁰ https://en.wikipedia.org/wiki/Tesla_Autopilot, 9th Jan., 2017

drive autonomously and hands were recommended to be kept in contact with the driving wheel at least with intervals of up to 3 minutes¹⁸¹. Considerable discussion ensued, particularly within one consumer organisation¹⁸². However, Tesla beta-tested their software in practice and was able to collect large amounts of road side data (maps) with the help of these beta-testers. In practice, Tesla can immediately sell autonomously driving cars in large numbers, when it becomes legally and practically permitted. The facility will be activated with a software update.

3.2.1.1 Liability issues prevent market access

As the examples above show, the automotive industry and new players are now actively taking positions in the evolving business of autonomous vehicles. Due to clear safety advantages and considerable CO₂ and pollution benefits, societies have no other options than to accept autonomous vehicles. Many countries hope that their industries could participate in the coming restructuring of automotive business.

Several countries have chosen to support the development of autonomous driving and cars, and their testing in general traffic is permitted. Typically, a human operator is needed to start manual driving immediately if requested by the automation system. Some countries allow teleoperation i.e. “distant driver” and/or require a specific insurance. The following countries/states allowed testing of autonomous vehicles on public roads during early 2017: California, Florida, Nevada, Michigan, Texas, Washington D.C. and Virginia of the United States, Australia, China, Ontario of Canada, Finland¹⁸³, France, Germany, Greece, Italy, Japan, Mexico, Netherlands, Sweden, United Kingdom, Singapore, Spain and Switzerland. The situation is changing rapidly. US updates were collected¹⁸⁴ e.g. by *The Council of State Governments*.

For example, Finland requires¹⁸⁵ among other things “a description of how road safety will be ensured”. California rapidly publishes¹⁸⁶ the intentions and the results of companies qualified to test autonomous driving. In Michigan¹⁸⁷, “The law also allows companies to use self-driving cars for ride-sharing services.”

¹⁸¹ <http://www.consumerreports.org/mercedes-benz/consumer-reports-tests-mercedes-semi-autonomous-drive-pilot-system/> & <http://www.techradar.com/news/car-tech/the-2017-mercedes-benz-e300-challenges-tesla-s-autopilot-with-drive-pilot-1324027>, 17th Jan., 2017

¹⁸² <http://www.consumerreports.org/tesla/tesla-autopilot-too-much-autonomy-too-soon/>, 10th Jan., 2017

¹⁸³ http://www.trafi.fi/en/road/automated_vehicle_trials, 10th Jan., 2017

¹⁸⁴ <http://knowledgecenter.csg.org/kc/content/state-laws-autonomous-vehicles>, 19th Jan., 2017

¹⁸⁵ http://www.trafi.fi/en/about_trafi/news/3395/automated_vehicle_trials_in_finland, 10th Jan., 2017

¹⁸⁶ <https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/testing>, 10th Jan., 2017

¹⁸⁷ <http://nordic.businessinsider.com/driverless-car-regulations-michigan-2016-12/>, 11th Jan., 2017

China may take the lead gradually, because the country is planning a **single**¹⁸⁸ **standard** for autonomous vehicles. In addition, China will be the largest single market when fully autonomous vehicles dominate the new car markets. The USA is progressing in the same direction, i.e. the **U.S. Department of Transportation** has recommended¹⁸⁹ “a goal of generating a consistent national framework for the testing and deployment of highly automated vehicles”. The **European Road Transport Research Advisory Council** has published the *Automated Driving Roadmap*¹⁹⁰ updated by the related *Working Group on Connectivity and Automated Driving*¹⁹¹

Tesla is improving¹⁹² and acquiring followers:

- Mercedes-Benz/Daimler published¹⁹³ comparable ADAS functions in 2016. Their autopilot has also earned positive grades¹⁸¹.
- Volvo has its Pilot Assist¹⁹⁴. It appears to be improving gradually¹⁹⁵ and has become a practical driving assistant system.
- NuTonomy was testing¹⁹⁶ an autonomous taxi service in Singapore in 2016.

Tesla tested the sale of self-driving features as a relatively low-priced option, as a market introduction in an expensive luxury car. Mercedes-Benz and Volvo appear to be following the lead in pricing. Autonomy features will become key selling arguments, when a wide audience becomes familiar with the benefits, e.g. the low risk of accidents, autonomous parking and improved fuel economy, and when insurance savings are set. Mobility services such as shared autonomous shuttle buses in cities e.g. by Volkswagen¹⁹⁷ will rapidly increase the familiarity and technology adoption. True multimodality e.g. autonomous helicopters,¹⁹⁸ in

¹⁸⁸ http://www.handyshippingguide.com/shipping-news/china-to-set-single-standard-for-autonomous-cars-and-freight-trucks_7664, 12th Jan., 2017

¹⁸⁹ <https://www.transportation.gov/AV>, 12th Jan., 2017

¹⁹⁰ http://www.ertrac.org/uploads/documentssearch/id38/ERTRAC_Automated-Driving-2015.pdf, 12th Jan., 2017

¹⁹¹ <http://www.ertrac.org/index.php?page=connectivity-and-automated-driving>, 12th Jan., 2017

¹⁹² <http://nordic.businessinsider.com/tesla-enhanced-autopilot-system-features-2017-1/>, 11th Jan., 2017

¹⁹³ <https://www.mercedes-benz.com/en/mercedes-benz/innovation/with-intelligent-drive-more-comfort-in-road-traffic/>, 10th Jan., 2017

¹⁹⁴ <http://support.volvocars.com/fit/cars/Pages/owners-manual.aspx?mc=v526hbat&my=2016&sw=15w46&article=548956727ac6edfbc0a80151522a4edc>, 10th Jan., 2017

¹⁹⁵ <https://techcrunch.com/2016/09/15/20-minute-hot-take-2017-volvo-s90-pilot-assist/>, 10th Jan., 2017

¹⁹⁶ <http://nutonomy.com/press.html>, 11th Jan., 2017

¹⁹⁷ <http://www.autoblog.com/2017/01/08/volkswagen-id-buzz-concept-autonomous-ev-microbus-8369232/>, 11th Jan., 2017

¹⁹⁸ <http://www.dpaonthenet.net/article/132159/Aerospace-innovation--why-drive--when-you-can-fly-.aspx> & <http://www.dpaonthenet.net/article/132200/Pop-up-capsule-could-be-the-future-of-urban-transportation.aspx>, 13th March, 2017

combination with autonomous taxi cars, will increase the general throughput of public transport.

Uber has well opened the market of “ride-hailing” and the other players are investing heavily to master the evolving market – as Business Insider¹⁹⁹ well visualised. Autonomous vehicles are very important to the ride-hailing business, as Uber currently pays 80% of its turnover to human drivers. Uber could keep that slice to itself with autonomous shuttle buses. Automotive industry invests heavily in ride-hailing, because it will open business in the autonomous vehicles and mobility services (i.e. MaaS²⁰⁰) to which the automotive industry is heading²⁰¹. Parcel and food logistics in cities will be the next interesting application as tested already by e.g. Uber²⁰² with human drivers. And, of course, local travelling possibilities of persons unable to drive e.g. elderly and handicapped persons, children and drivers under the influence of alcohol, will increase when fully autonomous vehicles are allowed.

Several estimates on evolution of autonomous vehicles have been given. Frost & Sullivan estimated (N.N., 2016F) the autonomous driving market in North America as (in the Figure 17) “North America is likely to have more than 3.5 million highly automated vehicles by 2030”. SAE levels were used. A similar market size was estimated for Europe: “10%–15% vehicles in Europe will be highly automated by 2030” (N.N., 2016F).

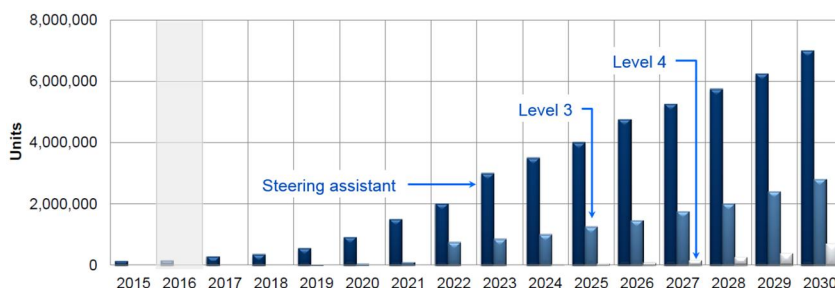


Figure 17 Estimates on “steering assistants” and autonomous cars in North America by Frost & Sullivan (N.N., 2016F)

¹⁹⁹ <http://nordic.businessinsider.com/web-of-ride-hailing-investments-2016-12/>, 11th Jan., 2017

²⁰⁰ https://en.wikipedia.org/wiki/Transportation_as_a_Service, 11th Jan., 2017

²⁰¹ <http://www.autoblog.com/2015/09/18/bmw-mercedes-ponder-challengers-uber/>, 11th Jan., 2017

²⁰² <https://newsroom.uber.com/us-new-york/a-reliable-ride-for-your-deliveries/> & <http://venturebeat.com/2015/01/26/uber-cancels-on-demand-delivery-service-pilot-uberessentials/>, 11th Jan., 2017

As there are currently legal barriers to the adoption of autonomous vehicles, it is difficult to give estimates on their adoption. For example, the following are given:

- The Boston Consulting Group²⁰³ (2017): Global market estimated to grow from **42 billion USD in 2025** to **77 billion in 2035**. Half of that market will be for **fully autonomous (12 million vehicles)** vehicles in 2035. The number of **partially autonomous** vehicles would be **18 million** in 2035.
- Juniper Research²⁰⁴ (2016): *“annual production of self-driving cars will reach **14.5 million in 2025**, up significantly from only a few thousands in 2020, to give a global installed base of more than 22 million consumer vehicles by 2025.”*
- Frost & Sullivan (N.N., 2015C): *“... **by 2030**, it is likely that autonomous vehicles will have **replaced the majority of human taxi drivers and truck drivers.**”*

Tesla and Google/Waymo²⁰⁵ (*“our cars have self-driven over two million miles on public roads across four U.S. cities”*) have actively published how much their vehicles have driven in autonomous mode as they are also legally required¹⁸⁶ to do.

It has been noticed that **human errors** are the most typical reasons for traffic accidents. Singh (2015) reported that **94% of** critical reasons of *“a weighted sample of 5 470 crashes”* studied in detail were related to drivers and their errors. Similar earlier results have also been listed²⁰⁶.

As the societal benefits of autonomous vehicles appear to be huge when counting only saved lives and the reduced number of handicapped persons, it seems odd that they are not accepted at a more rapid rate. As Elon Musk stated²⁰⁷ in 2016:

“... anything that keeps us from adopting driverless cars is, in effect, killing people.”

Autonomous vehicles will (try to) follow the traffic rules and do not get sick or fall asleep. They will also optimise their routes automatically according to traffic jams, working hours and actions of other vehicles. This leads to energy and time savings.

²⁰³ <https://www.bcg.com/expertise/industries/automotive/autonomous-vehicle-adoption-study.aspx>, 11th Jan., 2017

²⁰⁴ <https://www.juniperresearch.com/press/press-releases/taxi-sector-to-lead-self-driving-market-to-over-22>, 11th Jan., 2017

²⁰⁵ <https://waymo.com/faq/>, 12th Jan., 2017

²⁰⁶ <http://cyberlaw.stanford.edu/blog/2013/12/human-error-cause-vehicle-crashes>, 12th Jan., 2017

²⁰⁷ <http://www.theverge.com/2016/10/19/13341306/elon-musk-negative-media-autonomous-vehicles-killing-people>, 13th Jan., 2017

The slow adoption of autonomous vehicles is obviously due to three basic reasons:

1. Requirement for absolute safety
2. Product liability issues
3. Low rate of change of traffic rules

As traffic is a profession and occupation for many people, typical **safety at work** requirements are also in force with autonomous vehicles and related technology. Accidents also occur during work in factories, but there are common (Occupational safety and health, OSH) practices to report and study all work-related accidents. Related authorities may also stop professional usage of equipment or even technology that they consider unsafe.

“... 35 092 people died on U.S. roadways¹⁸⁹ in 2015.” By comparison, the number of fatal work injuries in U.S. has been about 4 800 in recent years²⁰⁸. About 1 600 of them occurred on roadways. Fatalities in traffic globally are estimated to about 1.2 million per annum.

Adam Thierer²⁰⁹ concluded:

*“In 2013, the Eno Center for Transportation forecasted²¹⁰ that even at just a conservative 10-percent penetration rate, autonomous vehicles would help save more than 1,000 lives per year and result in comprehensive cost savings for society of almost \$18 billion annually. But if we achieved **90 percent adoption**, the group estimates almost **22,000 lives would be saved yearly**, and society would garner a staggering **\$350 billion in cost savings.**”*

Understanding the numbers above leads to the conclusion that autonomous vehicles are **inevitable**, with rapid change occurring when their safety can be guaranteed or considered officially far safer than manual driving.

As all nations have traditionally made efforts to guarantee the safety of all equipment and services sold in the country, people tend to assume that all equipment is safe in all use cases. This is actually not true, when software, electronics and human design of safety systems are involved. Robots are machines and machines make or may make mistakes in the case of physical (component) failures, software error or fault in human operation. The consequences may be fatal, as in Michigan²¹¹ 2015.

²⁰⁸ <https://www.bls.gov/iif/oshwc/foi/cfch0014.pdf>, 13th Jan., 2017

²⁰⁹ http://www.slate.com/articles/technology/future_tense/2016/06/if_a_driverless_car_crashes_who_is_liable.html, 16th Jan., 2018

²¹⁰ <https://www.enotrans.org/etl-material/preparing-a-nation-for-autonomous-vehicles-opportunities-barriers-and-policy-recommendations/>, 16th Jan., 2017

²¹¹ https://www.theregister.co.uk/2017/03/11/autobot_makers_sued_over_technicians_death, 14th March, 2017

Automation and electronics manufacturers try to make their systems safe, so that in case of any malfunction, the systems stop via safe sub-states. As the malfunction may occur in the sub-systems dealing with safety observation, the systems become complex and duplicated. Independent duplicated or multiplied safety systems are in operation in parallel, i.e. simultaneously.

Proving that these complex systems are safe in all use cases, including potential malfunctions, is an arduous task and requires a large number of repeatable testing scenarios. Therefore Google/Waymo and others have been testing their autonomous vehicles in normal traffic with a driver as a safety back-up, after much testing at closed testing tracks. Frequent software updates require constantly new and repeatable tests.

As somebody has to be in charge of any products sold, automotive brands have to take full responsibility for their products in order to open the markets of autonomous vehicles. Volvo took the lead in 2015:

“Volvo will accept full liability²¹² whenever one of its cars is in autonomous mode...”

Others²¹³ will most probably follow with similar announcements. Volvo has an understanding²¹⁴ that they have duplicated (equipment and in software) sufficiently:

*“Autopilot will include so **many redundant and backup systems** – duplicate cameras, radars, batteries, brakes, computers, steering actuators – that a human driver will never need to intervene and thus cannot be at fault.*

“Whatever system fails, the car should still have the ability to bring itself to a safe stop.”

Volvo may take the liability towards the end user, but certainly also transfers the liability to its component and software providers. This transfer will occur in advance in contracts and will be difficult to agree, as some countries maintain fines as punishment, the size of which depends on the turnover of the liable company, not on the damages caused. That is also one reason why large companies establish dedicated daughter companies to be in charge of the technology of autonomous vehicles. The Google-Alphabet-Waymo chain is a good example. In addition, some countries require special insurances to cover potential extra liability costs of autonomous vehicles.

Strangely enough, courts do not normally accept declared liability as such, but liabilities are considered according to the prevailing laws in each country and in a

²¹² <https://www.media.volvocars.com/global/en-gb/media/pressreleases/167975/us-urged-to-establish-nationwide-federal-guidelines-for-autonomous-driving>, 12th Jan., 2017

²¹³ <http://jalopnik.com/mercedes-google-volvo-to-accept-liability-when-their-1735170893>, 20th Jan., 2017

²¹⁴ <https://www.scientificamerican.com/article/who-s-responsible-when-a-self-driving-car-crashes/>, 19th Jan., 2017

traditional manner in the case of traffic accidents. For example, the Michigan laws²¹⁵ transfer the liability towards the provider of the faulty component or software. California requires 5 million USD dedicated insurance²¹⁶ on each autonomous vehicle. Several countries and interesting markets e.g. the USA. use the concept of “common law²¹⁷” in which an earlier decision of court becomes “law in practice” in combination with underlying rules, earlier court decisions and laws. The decisions rule to a great extent in the case of evolving new technology. Insurance to cover liabilities on autonomous vehicles will therefore most probably be mandatory until proper laws on autonomous vehicles are accepted.

It is therefore hardly surprising that there has been considerable debate and discussion on liability issues and laws on autonomous vehicles e.g. in the USA²¹⁸ and in the UK²¹⁹. Some countries appear to accept computers as a driver and some do not. There is a need for general and internationally accepted laws on autonomous vehicles and their liability issues.

Safety is the issue. As Barack Obama wrote²²⁰:

“If a self-driving car isn’t safe, we have the authority to pull it off the road ... We won’t hesitate to protect the American public’s safety.”

Ford has noticed¹³³ that the most critical factor in driving - is the driver.

“The struggle to prevent snoozing-while-cruising has yielded a radical decision: Ford will venture to take the human out of the loop by removing the steering wheel, brake and gas pedals from its driverless cars debuting in 2021.”

Of course, there are international and widely adopted agreements on road traffic. Among them is the “Geneva Convention on Road Traffic²²¹” (including 2006 amendments), which says:

*“Driver’ means any **person** who drives a ... vehicle, ...
Every moving vehicle or combination of vehicles **shall***

²¹⁵ [http://www.mlive.com/business/west-](http://www.mlive.com/business/west-michigan/index.ssf/2017/01/autonomous_vehicles_will_cut_a.html)

[michigan/index.ssf/2017/01/autonomous_vehicles_will_cut_a.html](http://www.mlive.com/business/west-michigan/index.ssf/2017/01/autonomous_vehicles_will_cut_a.html), 13th Jan., 2017

²¹⁶ https://www.dmv.ca.gov/portal/dmv/forms/about/lad/pdfs/auto_veh2/adopted_txt.pdf, 16th Jan., 2017

²¹⁷ https://en.wikipedia.org/wiki/Common_law, 16th Jan., 2017

²¹⁸ <https://www.brookings.edu/research/products-liability-and-driverless-cars-issues-and-guiding-principles-for-legislation/>, <http://jalopnik.com/mercedes-google-volvo-to-accept-liability-when-their-1735170893>, &

<http://digitalcommons.law.scu.edu/lawreview/vol52/iss4/9/>, 19th Jan., 2017

²¹⁹ <https://www.gov.uk/government/publications/driverless-cars-in-the-uk-a-regulatory-review>, 20th Jan., 2017

²²⁰ <https://www.bloomberg.com/news/articles/2016-09-20/self-driving-cars-must-meet-15-benchmarks-in-new-u-s-guidance>, 3rd Jan., 2017

²²¹ <http://www.international-driving-permit.com/Convention-on-Road-Traffic/8-November-1968/EN/index.aspx>, 20th Jan., 2017

have a driver. ... Every driver shall at all times be able to control his vehicle. ... Every motor vehicle shall be equipped with a strong steering mechanism ...“

Clearly, the Geneva Convention has to be clarified on autonomous vehicles in order to guide or affect national legislation as the convention is supposed to do. It is typically utilised when cars move from one country to another. On the other hand, if a product is accepted in one EU country, it must be acceptable in all other EU countries.

The Geneva Convention allows amendments and changes. Changes to enable autonomous vehicles have been under discussion²²² for several years. They will – probably and hopefully – gradually affect national laws.

Safety issues are even more important with heavy traffic vehicles e.g. freight trucks (transport lorries). Semitrailers are quite difficult to drive in slippery conditions uphill and downhill. However, note that autonomous vehicles can measure friction and may stop before entering risky conditions. They will also obey instructions given by local road administration. Moreover, they will follow the maps. An autonomous truck would not have carried out the recent (2016) terrorist acts in Nice and Berlin.

3.2.1.2 How could autonomous vehicles be utilised in the Finnish elderly care system?

The section above shows that several organisations with considerable resources and numerous new players are developing autonomous vehicles. Governments also hope that their countries could benefit from the new evolving industry of autonomous vehicles. Therefore, it is obvious that autonomous vehicles will be legally and practically permitted by about 2019 in several countries, and soon thereafter in many others.

How could the elderly care system in Finland utilise autonomous vehicles? **Transporting patients** to medical laboratories or hospitals and care-related **food and parcel logistics** are potential initial applications.

There will be many shuttle bus companies using autonomous vehicles. Governments should hire or establish dispatching centres to take care of transporting persons to laboratories and hospitals in an optimal manner. Such a service requires considerable flexibility, because the travel possibilities of elderly persons may change despite an earlier agreed schedule. Using dedicated shuttle buses with a certain set of telepresence equipment may help to reduce costs. Dispatching centres will also activate individual trips with manually driven or autonomous taxicab vehicles.

Kela (The Social Insurance Institution of Finland) already has a dispatching system²²³ and a related invoicing system for health-related government-supported

²²² <http://www.lexology.com/library/detail.aspx?g=7a3c3059-215a-4ebb-8122-0779bb465f6e> & <http://www.unece.org/fileadmin/DAM/trans/doc/2014/wp29grrf/GRRF-78-14e.pdf>, 31st Jan., 2017

²²³ <http://www.kela.fi/web/en/how-to-book-a-taxi>, 13th Feb., 2017

transportation. Utilising autonomous vehicles and several persons in the vehicles in an optimal manner would be a natural improvement to the Kela dispatching system. Practical planning and test trials are needed to establish the new autonomous service options in an optimal manner.

Elderly people and the government both wish unanimously that we could all stay at home as long as possible. There are an increasing number of elderly people needing assistance in daily living e.g. as shown in the Figure 28 below on page 69. Typically, elderly people are assisted at home by:

- meal deliveries in insulated boxes
- delivery of medication e.g. as sorted to a “plastic cord of bags”, with a printed schedule on each bag
- visits by nurses e.g. to check status, washing and medical assistance
- (rare) visits by a geriatrist to make long term care planning

Autonomous vehicles could deliver meal and medication boxes to elderly people according to an optimised schedule and route. Such a route could be generated each morning for each vehicle. Changes during travel would also be possible on request.

Many elderly people in Finland live at home in sparsely populated areas. It is common to combine home care tasks together so that one person using typically a vehicle visits the elderly person and performs all the necessary duties at his or her home. New players are entering this business field, as there is a clear trend to enable competition and cut governmental costs in home care services. In addition to delivering mail, the Finnish mail service (Posti) has acquired nurses²²⁴ to perform home care. Posti already delivers meals as ordered by municipalities.

The idea here is to separate logistics and personal home care so that autonomous vehicles make the routine transport to those home care customers that are able to get out to pick his/her parcel from the autonomous vehicle, carry it home, open and utilise it. The operator could help the these customer by the vehicle and home via telepresence. This would mean that visiting nurses could provide personal assistance for longer periods to home care customers.

Preparing the service to a practical level requires planning and testing of existing technologies e.g. delivery of the container (i.e. box) storage and delivery tray to the vehicle, route optimisation software, container design, telepresence system design and supervisory centre software design. In addition, meal preparation partners need to design their services to match autonomous vehicle deliveries. Capacity planning is also necessary to estimate the cost level. This is needed for decisions to proceed, e.g. to define the number of vehicles to cover a certain area.

There will be much discussion about autonomous vehicles – even and also in the Finnish Parliament²²⁵. They could also utilise the estimates of the planning phase.

²²⁴ http://www.posti.com/english/current/2017/20170110_hoiva.html, 14th Feb., 2017

²²⁵ <https://www.eduskunta.fi/EN/Pages/default.aspx>, 14th Feb., 2017

It is wise to estimate that autonomous vehicles will be utilised in Finland from the year 2020. This means that the planning and test phase with human operators in the vehicle should be started by the end of 2017.

Figure 18 shows a concept view of the operation of a meal delivery supervisory interface. The telepresence view should be available in parallel. The base map is from OpenStreetMap²²⁶. Note that the vehicle is available for about 18 hours a day for other duties after the meal boxes have been delivered.

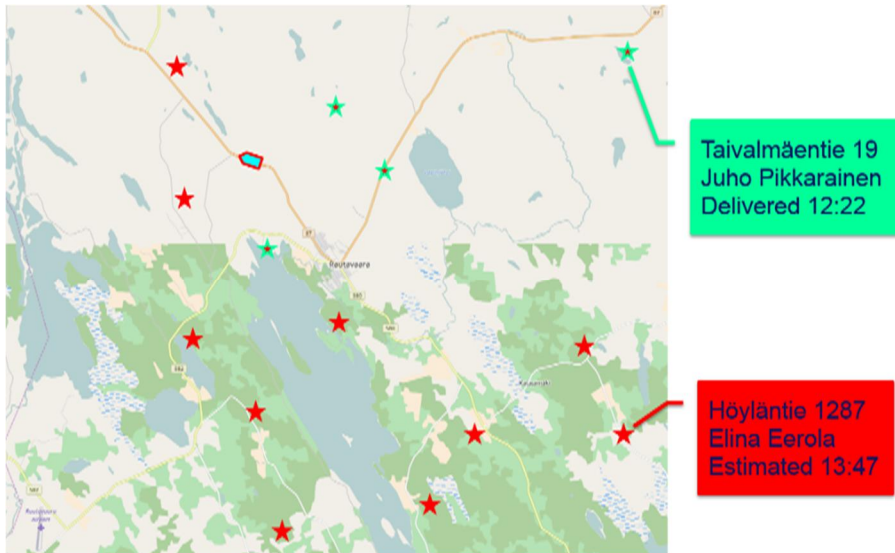


Figure 18 Concept view on meal delivery route execution and planning view in a sparsely populated area in Finland (© OpenStreetMap contributors, 2017)

3.2.2 Autonomous industrial vehicles

Autonomous vehicles have been used in industrial applications since the 1970s. There are many occupational safety requirements, which have been fulfilled in general. The first large applications were AGVs (Automated Guided Vehicles²²⁷) for storage and manufacturing logistics applications.

Figure 19 (by AGVExpertJS, 2014²²⁸) shows an example of an AGV that can well be used in hospitals or elderly care dormitories for logistics. This version requires that somebody or something picks and loads the items from and to the shelves.

²²⁶ <https://www.openstreetmap.org/copyright/en>, 14th Feb., 2017

²²⁷ https://en.wikipedia.org/wiki/Automated_guided_vehicle, 14th Feb., 2017

²²⁸ https://en.wikipedia.org/wiki/File:Packmobile_with_trailer_AGV,_Egemin_Automation.jpg, 6th June, 2017

There are other versions e.g. by Oceaneering²²⁹ and MiR²³⁰ that have motorised rolls to do unloading and loading. Robot arms at the transfer sites can load/unload parcels, boxes and containers. Blue Ocean Robotics has rather similar TUG²³¹ robots (i.e. AGV vehicles) for hospital logistics. Saviok introduced autonomous Relay²³² vehicles for indoor point-to-point logistics, and Starship Technologies²³³ for outdoor. TeleRetail²³⁴ aims for both. Yelp Eat24 is testing²³⁵ autonomous Marble delivery vehicles to move grocery bags.

It was soon understood that industrial occupational safety requirements can be fulfilled by separating autonomous vehicles and human workers. Another evolved option was to limit the speed of autonomous vehicles to be so slow that reliable electromechanical bumpers would stop the vehicle and nothing or nobody would be harmed due to unintended collision. The strategy has been successful so far: this writer does not know of any fatal accident caused by an industrial autonomous vehicle.

VTT joined the development of industrial autonomous vehicles in 1985.

Methods and results were published e.g. by Lehtinen et al. (2000). The following application fields were described (Lehtinen et al., 2000):

- Underground mining
- Cladding
- Drilling rig
- Agricultural tractor
- Factory logistics
- Heavy transportation
- Container ports

Wood harvesting was also considered, but only using teleoperation, because autonomous wood harvesting in forests is still both economically and technically



Figure 19 An AGV by Egemin, AGVExpertJS (2014)

²²⁹ <http://www.oceaneering.com/agv/agv-solutions/>, 24th Feb., 2017

²³⁰ <http://www.mobile-industrial-robots.com/about-us/company-profile>, 18th April, 2017

²³¹ <http://www.blue-ocean-robotics.com/en/solutions/healthcare/logistic-robots/tug-for-hospital-logistics>, 14th Feb., 2017

²³² <http://www.saviok.com>, 6th April, 2017

²³³ <https://www.starship.xyz>, 6th April, 2017

²³⁴ <https://teleretail.com/>, 23rd May, 2017

²³⁵ http://www.robotictrends.com/article/marble_delivery_robots_yelp_eat24, 19th April, 2017

challenging. The other above listed applications have both autonomous and manually driven vehicles in industrial applications. The manually driven vehicles are still the clear majority. Examples of autonomous industrial vehicles in practical use or in prototype phase are given in the links below. These examples clarify the practical state of the art.

- Autonomous mining vehicles²³⁶ and rock drilling²³⁷
- Automated container vehicles²³⁸
- Cladding robot²³⁹ (announcement)
- Agricultural tractor²⁴⁰ (announcement)
- Pallet transporting AGVs²⁴¹ as an example of factory logistics
- Heavy industrial transportation²⁴²
- Long-haul truck logistics¹⁷¹

The methods used in industrial autonomous vehicles are well available to health care applications. The main difference is that in industry, autonomous vehicles can move in closed areas where people must not enter – typically, training is required for permission to enter the area of autonomous operation and/or the operation is stopped when any person enters the working area of autonomous vehicles. Then the safety issues are easier.

AGVs like TUG²³¹ can well be applied to the parcel logistics of a hospital or care dormitory. There are standards (i.e. requirements) concerning how to prevent collisions with human persons working in the same area. It is wise to utilise the same (usually) underground corridors for both human and automated logistics. Fluent operation features e.g. passing places are easy to design and organise, when logistics (automated and manual) are well planned before the construction starts. AGVs cannot cope with stairs, but can use elevators (lifts) if taken into account during the planning stage of the elevators.

²³⁶ <http://www.navitecsystems.com/wordpress/references/sandvik/> & <http://mining.sandvik.com/en/products/equipment/mine-automation-systems> & <https://www.technologyreview.com/s/603170/mining-24-hours-a-day-with-robots/>, 6th March, 2017

²³⁷ <http://mining.sandvik.com/en/products/equipment/mine-automation-systems/equipment-automation/automine-surface-drilling> & http://www.atlascopco.co.uk/en-uk/mrba/customer-stories/stories---ads/Powered_by_Automation_Pit_Viper, 6th March, 2017

²³⁸ <https://www.itnews.com.au/news/port-of-melbourne-automation-project-scooped-by-finnish-giant-399562>, 6th March, 2017

²³⁹ <http://digital.di.se/artikel/golvlaggarrobot-tar-in-kapital-infor-lansering>, 6th March, 2017

²⁴⁰ <http://www.cnbc.com/2016/09/16/future-of-farming-driverless-tractors-ag-robots.html> & <http://media.cnhindustrial.com/EMEA/CNH-INDUSTRIAL-CORPORATE/cnh-industrial-brands-reveal-concept-autonomous-tractor-development--driverless-technology-to-boost-/s/a2259742-061a-412a-8a12-d307dbaedd88>, 7th march, 2017

²⁴¹ <http://www.swisslog.com/en/Products/WDS/Automated-Guided-Vehicles>, 7th march, 2017

²⁴² <http://www.navitecsystems.com/wordpress/references/skb/>, 7th march, 2017

3.3 Care robots

The IFR¹¹² has estimated²⁴³:

*“Strong growth is reported in sales of handicap **assistive robots** and for the elderly. At 4,700 units (2015), the sales volume is still comparatively low. But sales figures are expected to rise to 37,500 units from 2016 to 2019. The rise in the value of sales will mirror this development: Sales in **2015** amounted to **USD 16.8 million** – a year-on-year increase of 34 percent. The total value is forecast to rise to **USD 97 million** between 2016 and 2019.”*

As there is easily a prejudice against care robots, it is actually a pleasure that discussion on this topic has started in Finland especially by nurses²⁴⁴ and care teachers²⁴⁵. The conclusion has been that care robots should be introduced carefully to voluntarily users and with benefits to all related care organisations and workers.

Ray et al. (2008) surveyed what household tasks people want and do not want to be done for them by (service) robots. Among the favourites were some quite easy tasks such as vacuum- and window-cleaning, security, laundry, snow removal, watering of plants and ironing. About 18% of interviewed persons preferred entertainment done by robot and 30% would not like robot to entertain them at all. This is surprising, because entertainment seem to be important part of evolving domestic assistance robots and intelligent speakers in 2017. There was obviously very little information or experience concerning social robots in 2008. This serves to emphasize the fact that introducing care robots must be carried out carefully, so that all interest groups and users see clear benefits and improvements in their situation. Mast et al. (2010) described processes concerning how to clarify needs and attitudes towards robots. They noticed needs for fall detection and automated emergency calls. Tulonen (2016) has written more on the clarification of needs and fears towards robots in Finnish.

Frost & Sullivan estimated (N.N., 2015B):

*“**22% of the world’s population will be of or above 60 years by 2020 ... The EU market for robots and devices assisting the senior population is estimated to reach \$14.7 billion by 2016. ... The global advanced remote patient monitoring market size was \$29.7 billion 2014.**”*

²⁴³ <https://ifr.org/ifr-press-releases/news/31-million-robots-helping-in-households-worldwide-by-2019>, 18th April, 2017

²⁴⁴ <https://sairaanhoitajat.fi/2015/hyoty-irti-roboteista-ja-tekoalysta/>, & <https://www.tehylehti.fi/fi/tyoelama/video-robotti-palvelutalossa-ettei-vaan-jaisi-alkuinnostuksen-jalkeen-polyttymaan>, 15th May, 2017 (in Finnish)

²⁴⁵ http://www.iltalehti.fi/terveys/201701112200052226_tr.shtml, 12th Jan., 2017 (in Finnish)

Robots may be, and are already used in care in several applications. Among them are

- robot-assisted physiotherapy (e.g. by REX Bionics²⁴⁶)
- remote discussions and diagnostics, teleoperation (e.g. by InTouch Technologies²⁴⁷. Note FDA clearance.)

Motivation for extended home care is clear in addition to the unanimous wishes of senior citizens to stay at home as long as possible. According to McWilliams (2015B):

*“U.S. expenditures on home healthcare approximately doubled, from \$39.8 billion in 2003 to \$79.3 billion by 2013. ... Between 2000 and 2012, the average cost of a **hospital stay** in the US increased from \$6,668 to **\$9,700** ... the **average daily cost of nursing home care** increased from \$129 in 2000 to **\$248 in 2012.**”*

Bedaf et al. (2015) listed tasks suitable for care robots supporting independent living according to the International Classification of Functioning (ICF) of WHO²⁴⁸. The list is a good reminder when planning support actions which could be performed by care robots. Bedaf et al. (2015) also found 107 robots for elderly people in their literature review. A few are still available. Mealtime Partners sell their feeding robot²⁴⁹ for about 8 000 USD in their web shop along with tens of other products. The turnover of Mealtime Partners was about 430 000 USD in 2015, with 6 persons employed in a family company. The pricing of Winsford™ Feeder²⁵⁰ is not available. Pricing of My Spoon²⁵¹ can be requested, although the related publication list contains publications only from 1992 to 2003. The feeding device Obi²⁵² is available on the market. The leasing costs²⁵³ of Obi are about 200 USD per month. Verily (of Google) is also interested in the feeding²⁵⁴ of “people with hand tremor or limited hand and arm mobility, in order to help them retain dignity, confidence and independence”. PARO²⁵⁵ (Figure 20) is a positive exception and appears to have entered the market in 2010 and is sold continuously and has been developed since²⁵⁶ 1993.

Although many of the development projects listed by Bedaf et al. (2015) have been discontinued, the developed technologies and software may pop up later

²⁴⁶ <http://www.rexbionics.com/rex-for-clinic-use>, 22nd July, 2016

²⁴⁷ <http://www.intouchhealth.com/our-solutions/patient-access/#vita>, 22nd July, 2016

²⁴⁸ https://en.wikipedia.org/wiki/World_Health_Organization, 25th Aug., 2016

²⁴⁹ <http://www.mealtimepartners.com/description/description.htm>, 30th Aug., 2016

²⁵⁰ https://www.ncmedical.com/item_223.html, 1st Sept., 2016

²⁵¹ <http://www.secom.co.jp/english/myspoon/>, 2nd Aug., 2016

²⁵² <https://meetobi.com>, 2nd May, 2017

²⁵³ <https://meetobi.com/funding/>, 2nd May, 2017

²⁵⁴ <https://verily.com/projects/interventions/liftware/>, 27th April, 2017

²⁵⁵ [https://en.wikipedia.org/wiki/Paro_\(robot\)](https://en.wikipedia.org/wiki/Paro_(robot)), 2nd Aug., 2016

²⁵⁶ http://www.aist.go.jp/aist_e/latest_research/2004/20041208_2/20041208_2.html, 1st Sept., 2016

elsewhere. For example, ASTRO, described by Cavallo et al. (2014), was developed to “deliver services to users, such as drug delivery, stand support, reminding, info-entertainment” and appears to have vanished from care robot discussions.

PARO (Figure 20, Biggs, 2005²⁵⁷) is a social robot seal intended to improve communication of and interaction with dementia patients. It has been tested globally and also in Finland by Mourujärvi & Ruuskanen (2013). Their results were encouraging:

“... Paro can be used as a method to promote communication and interaction and express feelings. Paro increases nurturing and care with the elderly suffering from dementia.”

The success of PARO will lead and has led to comparative products e.g. JustoCat²⁵⁸ selling²⁵⁹ also in Finland and robots for autism therapy e.g. PABI²⁶⁰.

It is quite straightforward to require that social robots for elderly care can understand and generate speech in the native language in each country.



Figure 20 PARO social robot (Biggs, 2005)

Rocon et al. (2007)

developed a robotic exoskeleton arm (WOTAS) to suppress the typical tremor of elderly people. The key question is to distinguish intended motion from tremor motion. This should be quite easily solvable now with training sequences and machine learning⁴⁸. Strengthening motions can also be performed finger by finger, e.g. using an SEM Glove²⁶¹.

It would be unwise to underestimate the exoskeleton market, which has been estimated²⁶² to reach 3.75 billion USD by 2021 and to grow annually by about 51% from 2016 to 2020.

The robotic wheelchair is a traditional topic in the field of autonomous vehicles. VTT also has extensive experience in this area (Virtanen et al., 2001).

²⁵⁷ https://commons.wikimedia.org/wiki/File:Paro_robot.jpg, 22nd May, 2017

²⁵⁸ <http://www.justocat.com>, 7th Dec., 2016

²⁵⁹ <http://www.innohoiva.fi/wp-content/uploads/JustoCat.pdf>, 7th Dec., 2016

²⁶⁰ http://www.robotictrends.com/article/pabi_penguin_robot_making_autism_therapy_more_affordable/medical, 19th April, 2017

²⁶¹ <http://bioservo.com/healthcare/product-portfolio/product-1/>, 13th Dec., 2016

²⁶² <https://www.therobotreport.com/news/45-research-reports-for-you-to-review#Exo>, 14th Dec., 2016

Much work can be carried out for an elderly person living at home via a tablet, if it is located correctly in the home. Robotic motion devices moving a tablet in a home are easily developed. The Double robot listed in the Table 2 (page 7) is an example.

Notifications to take medicines, and video calls with relatives and medical personnel, are ideal tasks for a "moving tablet" in support of elderly people. Both the inhabitant or teleoperating nurse or relative can activate the "tablet robots" to move around the home. These "tablet robots" will soon be general products aiming at communication with children and the elderly e.g. by Blue Frog Robotics²⁶³, Five Elements Robotics²⁶⁴, Inbot Technology²⁶⁵, VGo²⁶⁶, Suitable Technologies²⁶⁷, Mabu²⁶⁸ with Catalia Health platform, and Futurerobot²⁶⁹. As Pepper²⁷⁰ is a multi-purpose "semi-humanoid" social robot with a tablet with emotion detection skills, it can also be used in care applications. Clotet et al. (2016) have also developed such handles for the omnidirectional *Assistant Personal Robot (APR)* robot that would support walking of the inhabitant to the specified location at home. Integrated fall detection is also considered.

Tsuji et al. (2015) used a sensor instrumented room, a service robot and instrumented slippers to detect what happens in the room. Their robot was able to detect a beverage bottle in the room and bring it to the inhabitant. Versions of SmartPal²⁷¹ robots of Yaskawa Electric (from 2007) are used. Privacy issues are also considered.



Figure 21 "Tablet robot" as a walker (Clotet et al., 2016)

²⁶³ <http://www.bluefrogrobotics.com>, 7th Nov., 2016

²⁶⁴ <http://5elementsrobotics.com/5e-virtual-rep/>, 21st April, 2017

²⁶⁵ <http://www.padbot.se>, 1st Sept., 2016

²⁶⁶ <http://www.vgocom.com>, 29th Nov., 2016

²⁶⁷ <https://suitabletech.com/beampro/>, 15th Dec., 2016

²⁶⁸ <http://www.cataliahealth.com/how-it-works>, 29th Nov., 2016

²⁶⁹ <http://www.futurerobot.com/new2/page/product01.php>, 1st Sept., 2016.

²⁷⁰ <https://www.ald.softbankrobotics.com/en/cool-robots/pepper>, 29th Nov., 2016

²⁷¹ <https://www.yaskawa.co.jp/en/newsrelease/technology/7035>, 24th Aug., 2016

The following projects related to elderly care have been registered (Table 3).

Table 3 Elderly care related projects registered to date

Name	Duration	Aim
ICT4Life ²⁷²	2016-19	... to provide new services for integrated care employing user-friendly ICT tools, ultimately increasing patients with Parkinson's, Alzheimer's and other dementias and their caregivers' quality of life and autonomy at home.
CHIRON ²⁷³	2016-18	Care at Home using Intelligent Robotic Omni-functional Nodes, longer independent living
INOV CARE ²⁷⁴	2016-18	Physical activity monitoring through wearable technology, Neurological condition evaluation through mobile Smartphones, and Self-management care network.
SUSTAIN ²⁷⁵	2015-19	Sustainable tailored integrated care for older people in Europe living at home and long-term care centres
ENRICHME ²⁷⁶	2015-18	ENabling Robot and assisted living environment for Independent Care and Health Monitoring of the Elderly
GrowMeUp ²⁷⁷	2015-18	To provide an affordable robot that will be able to learn from older people's routines and habits.
I-SUPPORT ²⁷⁸	2015-18	Robot assistant for showering and washing.
MARIO ²⁷⁹	2015-18	Assistive robot for dementia patients.
RADIO ²⁸⁰	2015-18	Health monitoring with assistive robot and smart living environment.
CAMI ²⁸¹	2015-18	Intelligent assistance and telepresence.
RAMCIP ²⁸²		Robotic Assistant for MCI Patients at home.

²⁷² http://www.ict4life.eu/?page_id=269, 22nd July, 2016

²⁷³ <http://www.designability.org.uk/researchproject/chiron-care-at-home-using-intelligent-robotic-omni-functional-nodes/>, 7th Nov., 2016

²⁷⁴ <http://www.aal-europe.eu/projects/innovcare/>, 7th Dec., 2016

²⁷⁵ <http://www.sustain-eu.org/>, 16th Nov., 2016

²⁷⁶ <http://www.enrichme.eu/wordpress/about/>, 22nd July, 2016

²⁷⁷ <http://www.growmeup.eu/>, 2nd Sept., 2016

²⁷⁸ <http://www.i-support-project.eu/the-project/>, 2nd Sept., 2016

²⁷⁹ <http://www.mario-project.eu/>, 2nd Sept., 2016

²⁸⁰ <http://www.radio-project.eu/>, 2nd Sept., 2016

²⁸¹ <http://www.aal-europe.eu/projects/cami/>, 2nd Sept., 2016

²⁸² <http://www.ramcip-project.eu>, 2nd Sept., 2016

AXO-SUIT ²⁸³	2014-17	Exoskeleton for daily use.
SALIG++ ²⁸⁴	2014-17	Telepresence, platform for independent living.
Robotic Devices for Care ²⁸⁵		Identify key needs and implementation of the equipment at actual sites.
ALFRED ²⁸⁶	2013-16	Interactive Assistant for Independent Living and Active Ageing, platform, voice driven assistant
VictoryaHome ²⁸⁷	2013-16	Telepresence and automation for independent living
Patient@home ²⁸⁸	2012-2018	Development of welfare technology to support the hospitalisation of patients in their own home
Robot-Era ²⁸⁹	2012-15	Robots for independent living
SILVER ¹²	2012-15	Searches for new technologies to assist elderly people in their everyday lives.
Giraffplus ²⁹⁰	2012-14	Tablet robot with body sensors, video discussions, fall detection and tele-operation.
TSR ²⁹¹	2012 (?)	Tele-operated robot for home care
HOBBIT ²⁹²	2011-15	To develop a socially assistive robot for the elderly
DALi ²⁹³	2011-14	To develop an assistive walker that understands the home environment
SRS ²⁹⁴	2010-13	Tele-operated support and home care, semi-autonomy, machine-learning.
ALIZ-E ²⁹⁵	2010-2014	To build artificial intelligence (AI) for small social robots
ROBIN ²⁹⁶	2010-2012	To deliver user-driven innovations in robotics at hospital level

²⁸³ <http://www.axo-suit.eu/>, <http://www.aal-europe.eu/projects/axo-suit/>, 3rd Nov., 2016

²⁸⁴ <http://www.aal-europe.eu/projects/salig/>, 2nd Sept., 2016

²⁸⁵ <http://robotcare.jp/?lang=en>, 1st Sept., 2016

²⁸⁶ <http://alfred.eu/>, 1st Sept., 2016

²⁸⁷ <http://www.victoryahome.eu/be-well-victoryahome-create-possibilities.5480465.html>, 2nd Sept., 2016

²⁸⁸ <http://en.robocluster.dk/projects/patient@home.aspx> & <http://www.en.patientathome.dk>, 29th April, 2017

²⁸⁹ <http://www.robot-era.eu/robotera/>, 25th Aug., 2016

²⁹⁰ <http://www.giraffplus.eu/>, 25th Aug., 2016

²⁹¹ <http://www.win.tue.nl/tsr/eng/index.html>, 5th Sept., 2016

²⁹² <http://hobbit.acin.tuwien.ac.at/>, 2nd Sept., 2016

²⁹³ <http://www.ict-dali.eu/dali/index.html>, 2nd Sept., 2016

²⁹⁴ <http://srs-project.eu/overview>, 25th Aug., 2016

²⁹⁵ <http://www.aliz-e.org/>, 25th Aug., 2016

²⁹⁶ <http://www.roboregion.eu/index.html>, 1st Sept., 2016

DOMEO²⁹⁷	2009-2012	Open robotic platform for the integration and adaptation of personalized homecare services, as well as cognitive and physical assistance.
AAL²⁹⁸	2008-2020	funds projects in public-private partnerships in the field of information and communication technology (ICT) for active and healthy ageing
CompanionAble²⁹⁹	2008-12	Robotic companion
Huggable³⁰⁰	2005-15	Robotic companion
Mobiserv³⁰¹	2009-13	Robotic support for independent living

Hendrich et al. (2015) described a domestic robot system for “ambient assisted living (AAL)” developed in Robot-Era (Figure 22). Note that the robot has a Kinova Jaco arm³⁰², a handle to “lead walk” the user or to assist him or her to sit down or get up, and an MS Kinect³³ motion sensor. Kinect is widely applicable in home care, although originally developed for gaming. See for example Vildjiounaite et al. (2014) on use of the Kinect. The Robot-Era system appears to be evolving continuously and several subsystems have been tested on it. Encouraging video clips on usage of the Jaco arm have been distributed e.g. when assisting handicapped persons³⁰³.



Figure 22 The Robot-Era domestic robot (Hendrich et al., 2015)

Note that the tray in Figure 22 is essential for small transportation tasks at home. A few items can be carried simultaneously on a tray. Efficient waste logistics should also be developed. AGVs³⁰⁴ dedicated to hospitals e.g. by Swisslog³⁰⁵ and Yujin Robot³⁰⁶ easily find applications in large elderly care homes.

Tang et al. (2015) described a “discussing” companion robot, which aims to display emotions and utilise gestures. A smartphone is used as a core and facial

²⁹⁷ <http://www.aal-domeo.eu/>, 2nd Sept., 2016

²⁹⁸ <http://www.aal-europe.eu/about/why-this-programme>, 7th Dec., 2016

²⁹⁹ <http://www.companionable.net/>, 22nd July, 2016

³⁰⁰ <http://robotic.media.mit.edu/portfolio/huggable/>, 25th Aug., 2016

³⁰¹ <http://www.mobiserv.info/>, 29 Aug., 2016

³⁰² <http://www.kinovarobotics.com/assistive-robotics/products/manipulation/>, 25th Aug., 2016

³⁰³ <https://www.youtube.com/watch?v=F8yiSwCQ6u4>, 18th April, 2017

³⁰⁴ https://en.wikipedia.org/wiki/Automated_guided_vehicle, 28th Dec., 2016

³⁰⁵ <http://www.swisslog.com/en/Products/HCS/Automated-Material-Transport/TransCar-Automated-Guided-Vehicles> & <http://www.swisslog.com/en/Products/HCS/Automated-Material-Transport/RoboCourier-Autonomous-Mobile-Robot>, 28th Dec., 2016

³⁰⁶ <http://qocart.yujinrobot.com/>, 28th Dec., 2016

expressions and two robotic hands to display gestures. Embedded sensors e.g. Kinect³³ are used to measure what is happening in the environment.

The evolving set of “personal home assistants” i.e. “tablet robots” like Jibo³⁰⁷, Asus Zenbo³⁰⁸, Autonomous³⁰⁹, Aido³¹⁰ and Samsung³¹¹ concepts can obviously be used for elderly care, but also to detect floor lying persons and to discuss with them to detect a response, provide telepresence, remind about medication, upload measurements or wearables and to detect intrusion, fire or smoke. Even “smart speakers” like Amazon Echo³¹² and Google Home³¹³ can be used by senior citizens at home. Smart speakers with their simple user interface appear³¹⁴ to have more demand compared to more expensive social and assistance robots. Over 10 million Amazon Echo units had been sold globally by 2017. Apple Siri³¹⁵ is available in 21 languages. Ubtech cleverly combine²⁴ the speaking and understanding capabilities of Amazon Echo/Alexa to its assistant robot.

The combination of wearable measurements, tablet robot (i.e. social robot) and central automatic supervision of the measurements of large groups of people appears to very fruitful for the future and for cost savings in health care. The concept is also shown in Figure 7 above and was outlined e.g. in the Guardian³¹⁶.

Researchers have noted that requests presented by social robots are accepted in a better manner than those presented by a tablet. Therefore, there are extra benefits besides motion capability in applying a robot that sends wearable measurements to central supervision. Frost & Sullivan outlined (N.N., 2016C) the benefits and the concept as shown in Figure 23 below.

Frost & Sullivan (N.N., 2016E) estimated 36% average annual growth in the “*Global Care Assistance and Automation Robots Market*”. There are 8 main themes to bear in mind:

- Rapid economic growth – especially after 2018 and in exoskeletons.
- Partnerships between robot manufacturers and hospitals/clinics to secure viability of applications.
- Automation impacts to workflows and, hence, care delivery.
- Need to enhance performance and rehabilitation of elderly patients and looming shortage of care workers will boost the personal robotics market growth.

³⁰⁷ <https://www.jibo.com/>, 29th Aug., 2016

³⁰⁸ <https://zenbo.asus.com/>, 29th Aug., 2016

³⁰⁹ <https://www.autonomous.ai/personal-robot>, 29th Aug., 2016

³¹⁰ <http://www.aidorobot.com/>, 29th Aug., 2016

³¹¹ <https://www.engadget.com/2016/04/27/otto-is-samsungs-cute-personal-assistant-robot/>, 29th Aug., 2016

³¹² https://en.wikipedia.org/wiki/Amazon_Echo, 13th Dec., 2016

³¹³ https://en.wikipedia.org/wiki/Google_Home, 13th Dec., 2016

³¹⁴ <https://www.therobotreport.com/news/some-social-robots-are-selling-well-others-are-failing>, 13th Dec., 2016

³¹⁵ <https://en.wikipedia.org/wiki/Siri>, 6th June, 2017

³¹⁶ <https://www.theguardian.com/technology/2016/nov/06/robot-could-be-grandmas-new-care-assistant>, 5th Dec., 2016

- Innovations in the field will occur more and more throughout the US and especially in Silicon Valley.
- Joint venture funding is well available for the topic.
- Restraining factors are low cost-effectiveness and lack of expertise.
- First-movers have and will have considerable advantages in each application, as the market is at an initial stage in 2017.

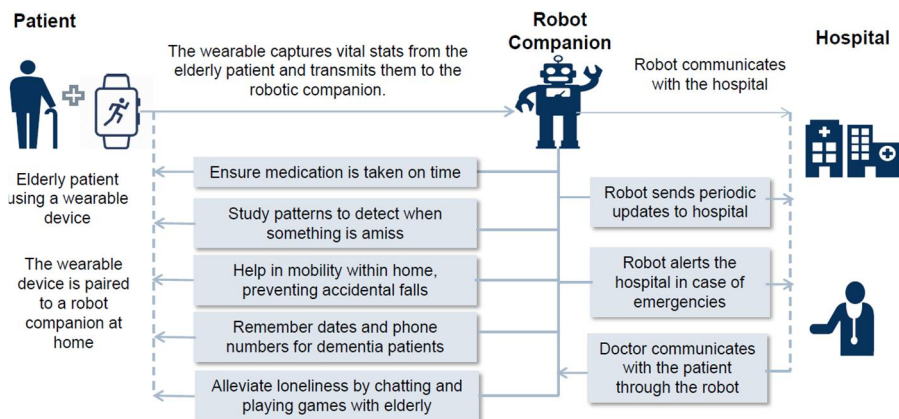


Figure 23 Multifunctional robot companion in elderly care (N.N., 2016C, Copyright: Frost & Sullivan)

The Japanese construction company Daiwa House sells or leases several care robots and care automation equipment³¹⁷. Obviously easy access to such equipment supports their construction business.

Robohub has collected³¹⁸ photos and videos of care robots.

3.3.1 What factors prevent wider exploitation of care robots?

There appear to be many benefits in care robots and related automation applications. However, they are still quite rare in practice. The main reasons for that, i.e. the main difficulties in applying care robots, are:

- High development costs for robot applications that provide benefits for all interest groups and patients. Human labour costs and the costs of the traditional way of work appear to be lower than the development costs.

³¹⁷ <https://translate.google.fi/translate?sl=ja&tl=en&js=y&prev=t&hl=fi&ie=UTF-8&u=http%3A%2F%2Fwww.daiwahouse.co.jp%2Frobot%2Findex.html&edit-text=>, 6th March, 2017

³¹⁸ <http://robhub.org/robots-that-may-help-you-in-your-silver-age/>, 18th April, 2017

- Privacy concerns.
- Fragility of elderly citizens.
- Complicity of elderly care environments and task. Robot technology is more easily monetised in other simpler environments and tasks.
- Only mass adoption and mass production will enable the low production costs that are necessary to open elderly care markets and to duplicate applications in large number. This is actually a hen-and-egg-problem: high production numbers are needed to justify the high development costs.

3.3.2 Dedicated or general care robots

It might be considered easy to develop one multi-talented personal robot with multiple functions to care for an elderly person. However, the different types of desired or even necessary care functions are actually endless. A robot that can move itself, the cared person and the tools and material necessary for all care support operations is actually a technical impossibility. The care environment is typically planned for human workers. The ideal care robot would be a humanoid robot with 10-fold strength and durability. But this is practically impossible. Therefore, most of the care robots described in this document have a single or a few functions that they use to give service.

Fortunately, there are many dedicated appliances and accessories to help elderly persons – i.e. most of us in the future – when they – and we – lose the accuracy of motions and strengths. Any robot of an automated device would have difficulties to help in the operations that would also extend the independent periods of persons living at home. Examples of simple equipment are:

- Putting socks on. *Full of Life* has *Extendable Sock Aid*³¹⁹ for that.
- Extra³²⁰ support for entering and departing vehicles

Examples of dedicated care robots (not described elsewhere in this document) are:

- Automated shower cabin Poseidon³²¹ of Robotics Care AB. If the person can independently undress and move to a wheelchair, he or she can also wash in/with the automated cabin.

The key solution is to design any care robot so that it will perform well a group of interrelated care operations. Thus, use a single or combination of a few capabilities of the robot in as many care operations as possible.

³¹⁹ <http://www.fulloflife.com/product/extendable+sock+aid.do>, 6th March, 2017

³²⁰ <https://www.amazon.com/Stander-HandyBar-Automotive-Standing-Emergency/dp/B000GUKKMW>, 6th March, 2017

³²¹ <http://www.roboticscare.com/poseidon-innovation-quality-life/>, 13th Dec., 2016

Another necessity is to provide a software platform that enables a large number of developer (companies) to develop care services on top of the platform.

The Double robot listed in Table 2 (page 7) is a good example of a simple care robot with simple motion capabilities and several software platforms. Its tele-presence can be used to search the elderly person in question and discuss with him/her from a remote computer without practical delays. Obviously other developer companies can utilise the tablet screen to their interfaces (on agreement) in order to simplify the life of elderly persons at home. Home control applications such as those of Alarm.com³²² or Control4³²³ are natural examples. The IFTTT applet platform³²⁴ is a more general example. Double Robotics will soon realise that opening their interfaces to other software is an effective means to increase their sales.

Loomo³²⁵ of Segway is planned³²⁶ in Singapore to move elderly residents of a nursing home within the facility. Loomo could also monitor blood pressure³²⁷ of the residents.

INF Robotics³²⁸ is planning to support in the USA alone up to 12 million living elderly persons. Their robot Rudy can support³²⁹ with telemedicine, emergency alarm calls, medication reminders, carrying objects, social interactions and playing games. The estimated end user price is 5 000 USD.

Although EU has invested much support in the projects listed in Table 3 on page 51, it is difficult to find any related robots on the market. Perhaps the reason is the general complexity of the goals or missing integration to the environment, i.e. support of auxiliary systems. Section 3.3.4 on page 60 lists some potential barriers, any of which typically prevents massive exploitation.

The IFR has estimated the number of service robots³³⁰ installed in 2015. Care related findings are:

“Sales of robots for elderly and handicap assistance will be about 37,500 units in the period of 2016-2019. This market is expected to increase substantially within the next 20 years. ... Handicap assistance robots have taken off to the anticipated degree in the past few years. In 2015, a total of 4,713 robots were sold, up from 4.416 in 2014 – an

³²² <https://www.alarm.com/smart-home-solutions>, 6th March, 2017

³²³ <https://www.control4.com/solutions/products/control4-app>, 6th March, 2017

³²⁴ <https://ifttt.com/>, 6th March, 2017

³²⁵ <http://www.segwayrobotics.com/product> & <https://techcrunch.com/2017/01/05/segways-first-robot-launches-to-developer-partners/>, 19th April, 2017

³²⁶ <http://ieccetech.org/issue/2017-03/Robots-pick-up-the-challenge-of-home-care-needs>, 18th April, 2017

³²⁷ http://www.roboticstrends.com/article/loomo_robot_singapores_new_elderly_care_nurse, 18th April, 2017

³²⁸ <http://www.infrobotics.com/index.html>, 18th march, 2017

³²⁹ http://www.roboticstrends.com/article/rudy_assistive_robot_helps_elderly_age_in_place, 18th April, 2017

³³⁰ https://ifr.org/downloads/press/02_2016/Executive_Summary_Service_Robots_2016.pdf, 20th April, 2017

*increase of 7%. Numerous national research projects in many countries concentrate on this huge future market for service robots. ... The total value of sales of **medical robots increased to US\$ 1,463 million**, accounting for **32%** of the total sales value **of the professional service robots**. Medical robots are the most valuable service robots with an average unit price of about US\$ 1.0 million, including accessories and services. Therefore, suppliers of medical robots also provide leasing contracts for their robots. **Medical robots as well as logistic systems are well established service robots with a considerable growth potential.**"*

As lack of imagination is often a barrier preventing care robots, a list of successful examples of service robot applications is given:

- milking robots e.g. by BouMatic³³¹
- floor cleaning robots e.g. Braava³³² by iRobot, TASKI Intellibot³³³ and Robo 40 of Cleanfix³³⁴
- glass façade cleaning e.g. by Gekko³³⁵ of Serbot
- disinfection of hospitals with ultraviolet light by Xenex³³⁶
- (sewage) tube inspection robots by RedZone Robotics³³⁷
- autonomous tractor³³⁸ for agriculture by CNH (Case New Holland)
- strawberry picking³³⁹ by Harvest CROO Robotics

3.3.3 Effects of evolving sharing economy

Governments are fighting the increasing costs of elderly care and increasing numbers of elderly persons. On the other hand, there are an increasing number of unemployed persons in many economies.

Many unemployed and recently retired persons see the needs of assistance for elderly citizens, but governments are not able to provide for the elderly persons.

³³¹ <http://www.boumaticrobotics.com/en/milking/milking-robots/milking-robot-mr-d1/>, 5th April, 2017

³³² <https://www.witt-ltd.com/iRobot>, 5th April, 2017

³³³ <https://www.intellibotrobotics.com>, 5th April, 2017

³³⁴ http://www.cleanfix.com/en/products/cleaning-machines/robo/robo-40_p835, 5th April, 2017

³³⁵ <https://www.serbot.ch/en/products/facade-cleaning/gekko-facade>, 5th April, 2017

³³⁶ <https://xenex.com>, 29th April, 2017

³³⁷ <http://www.redzone.com/redzone-products>, 6th April, 2017

³³⁸ <http://media.cnhindustrial.com/EMEA/CNH-INDUSTRIAL-CORPORATE/cnh-industrial-brands-reveal-concept-autonomous-tractor-development--driverless-technology-to-boost-/s/a2259742-061a-412a-8a12-d307dbaedd88>, 29th April, 2017

³³⁹ <http://harvestcroorobotics.com>, 29th April, 2017

These people and companies selling related intermediate services have established different forms of “sharing economy³⁴⁰”. Freecycle³⁴¹ is an example. TaskRabbit³⁴² collects small household tasks and selects a “tasker” in the neighbourhood to do it. Payments are settled via the TaskRabbit app. In addition to requesting services from TaskRabbit, elderly persons could also offer services using the TaskRabbit.

La'Zooz³⁴³ is a blockchain powered smartphone application that aims to fill empty seats of vehicles in real-time. It appears to be available only in Android/Google platform and is owned by its users. Lyft³⁴⁴ is a commercial version of ridesharing with sharing economy features.

Crowdfunding³⁴⁵ is also a form of sharing economy. People can invest in socially beneficial projects even when an economical return is not likely. Crowdfunding is also used for charity. Examples are Kickstarter³⁴⁶ and Indiegogo³⁴⁷.

Governments are herewith suggested to release the good will of volunteers to improve their possibilities to help elderly persons in their neighbourhood by the following means:

- Establish a trustworthy mobile payment tool that elderly persons can trust and use. Trustworthy central banks should act on this, because there have been many warnings on giving account details to anybody or to utilise “pop-up payment methods”. It would be positive to hear news that an interchangeable blockchain³⁴⁸ version of the Euro has been developed for small payments.
- Establish an international connected network of market places to offer, sell, buy and exchange “assistive work hours” of individuals. Thus, the services enjoyed would be settled with work and naturally, with money in several cases. An elderly person could then “pay” for the meeting of their grandchildren in Melbourne by advising on savings in Helsinki.

³⁴⁰ https://en.wikipedia.org/wiki/Sharing_economy, 27th April, 2017

³⁴¹ <https://www.freecycle.org>, 27th April, 2017

³⁴² <https://www.taskrabbit.com/>, 27th April, 2017

³⁴³ <http://www.lazooz.net/>, 4th May, 2017

³⁴⁴ <https://www.lyft.com/>, 4th May, 2017

³⁴⁵ <https://en.wikipedia.org/wiki/Crowdfunding>, 27th April, 2017

³⁴⁶ <https://www.kickstarter.com/>, 27th April, 2017

³⁴⁷ <https://www.indiegogo.com>, 27th April, 2017

³⁴⁸ <https://en.wikipedia.org/wiki/Blockchain>, 22nd may, 2017

3.3.4 Requirements for wide exploitation

Joseph F. Engelberger³⁴⁹ developed the first industrial robots for the automotive industry in 1961 and continued in the robot business ever since, with ups and downs. During the end of his career he turned to robotic elderly care, in which he saw³⁵⁰ a promising future e.g. in 2006:

“I want money and partnerships with Panasonic, or Johnson & Johnson, Philips, or Siemens. They're in the business [of healthcare products], have deep pockets, and have what I need for the robot to be successful: 1. design and manufacturing capability and 2. marketing experience in the health and eldercare marketplace.”

Besides those listed by Engelberger, several other aspects are also necessary for industrial scale massive exploitation of new technologies, e.g. care robots and automation. Among such necessities are for example:

- The production numbers of systems and sub-systems should be big enough for mass production methods. Size of the production series should be as low as 1, because nothing can be produced before the order and care robot systems are typically tailored.
- Methods, equipment and interfaces should be clear and standardised. Then multiple providers will appear and competition will keep prices relatively low.
- Software should be generally applicable and rely on open and general platforms.
- Components should be designed for automated manufacturing and assembly.
- Simulation environments for application development.
- Large numbers of application houses for independent application development. The producer/manufacturer in charge must establish tools for the system houses to build and sell applications.
- There should be good connections to supporting systems, e.g. invoicing, logistics, elevators, smart home environment and customer data. In other words, good system integration is necessary.
- Persons working with the robots should see benefits, i.e. robots should genuinely assist in the work and not cause new problems. Use of the robot

³⁴⁹ https://en.wikipedia.org/wiki/Joseph_Engelberger, 26th April, 2017

³⁵⁰ <http://spectrum.ieee.org/automaton/robotics/home-robots/where-are-the-eldercare-robots>, 26th April, 2017

should be obvious to a person familiar with the work to be carried out and the tasks performed at the site.

- The organisation investing in the robot should see clear benefits resulting from the investment.
- There should be professional training on the usage of care robots for people typically working with them, i.e. nurses.
- The persons taken care of by care robots should be voluntary persons. They should also experience benefits from the use of robots in their care. Benefits may be tied for example to the following:
 - Improved access (e.g. via telepresence) to medical personnel
 - Peace of mind enabled by a trustworthy healthcare system supervising the state of health of an elderly person.
 - Activation of preventive healthcare.

In addition to the recommendations above, all related laws and rules for medical and care equipment and personnel should be followed. Valvira⁶⁰ wrote on request a statement³⁵¹ concerning the usage of automation, software and robots in care applications. Valvira appears to be aware of the growth in care related technologies and anticipates increasing demands in health care supervision also in that for care-related automation and robots. – It is gratifying to notice afterwards that this document follows rather well the opinions of Valvira written during early 2017.

3.4 Surgical robots

In robot-assisted surgery³⁵², the surgeon typically makes surgery by teleoperating the tool in the robot arm or controlling robot motions with a computer. See Titan Medical³⁵³ for an example. Robots can make miniature operations or point objects according to a 3D model of the patient more accurately than a human surgeon can. Robots have been taught even to make stitches, and the test results have been in the class of human surgeons, or better³⁵⁴.

Robots are becoming essential in several surgeries, e.g. in gynaecology and urology. Wilson (2016) of BCC Research estimated that surgical robots are now a 3.5 billion USD market annually. Such robots typically place, guide or hold medical instruments and tools.

³⁵¹ https://www.valvira.fi/documents/14444/92813/Lausunto_robotiikan_hyodyntaminen.pdf/f0745d7f-a9ee-4777-a73e-3099a0347bb8 (In Finnish, Dnro 6760/00.02.00.03/2016), 16th May, 2017

³⁵² https://en.wikipedia.org/wiki/Robot-assisted_surgery, 3rd April, 2017

³⁵³ <http://www.titanmedicalinc.com/technology>, 4th April, 2017

³⁵⁴ <http://spectrum.ieee.org/the-human-os/robotics/medical-robots/autonomous-robot-surgeon-bests-human-surgeons-in-world-first>, 15th Aug., 2016

Da Vinci Surgical System³⁵⁵ of Intuitive Surgical³⁵⁶ has been used with FDA clearance from the year 2000 in minimally invasive microsurgery (MIS) for e.g. prostatectomies, cardiac valve repair and gynaecologic surgical procedures. Several thousand Da Vinci robot systems are now in use globally.

Robotic haptic user interfaces are used and developed e.g. in the SMARTSurg³⁵⁷ project – to support surgeons to realise small motions with MIS instruments. Verb Surgical claims³⁵⁸ to aim towards considerable improvements of surgical robots e.g. with 3D AR interfaces. The Google company Verily is involved.

Hansen Medical³⁵⁹ also provides cardiac operation robots called *Sensei X robotic catheter*³⁶⁰. Medrobotics³⁶¹ provide catheter instruments to reach and operate on organs inside the human body. The tip equipped with multiuse tools can be directed by teleoperation. TransEnterix is introducing *SurgiBot System*³⁶², that will help surgeons to operate several instruments “*through a single incision*”.

For more information on MIS and “needle intervention” systems, see the review of Moon and Choi (2015).

AVRA has a dexterous medical robot arm which it is including in various medical concepts, e.g. facial skin resurfacing³⁶³ and laser treatments.

Surprisingly, orthopaedic robot systems are routinely used in large operations such as knee and hip replacements and spine surgery. Laxmi (2017) of BCC Research estimated that the global market for orthopaedic robot systems was 11.6 billion USD in 2016 and will increase annually by about 8% to 17 billion USD in 2021. The reason for the success is obvious: robots can cut bone more accurately according to the 3D models than a human doctor. Healing is faster with tightly installed implants.

Examples of orthopaedic robot systems are the original ROBODOC³⁶⁴ of Curexo, Mako³⁶⁵ of Stryker Corp., NAVIO Surgical System³⁶⁶ of Smith & Nephew, Mazor Robotics³⁶⁷, THINK Surgical³⁶⁸ and OMNIBotics³⁶⁹ of OMNI.

³⁵⁵ https://en.wikipedia.org/wiki/Da_Vinci_Surgical_System, 3rd April, 2017

³⁵⁶ <http://www.davincisurgery.com/da-vinci-surgery/da-vinci-surgical-system/>, 17th April, 2017

³⁵⁷ <http://www.smartsurg-project.eu/>, 17th April, 2017

³⁵⁸ <http://www.verbsurgical.com/media/archived-press-releases/verb-surgical-demonstrates-digital-surgery-prototype-to-partners/>, 27th April, 2017

³⁵⁹ <http://www.hansenmedical.com/us/en>, 3rd April, 2017

³⁶⁰ <http://www.hansenmedical.com/us/en/cardiac-arrhythmia/sensei-robotic-system/product-overview>, 3rd April, 2017

³⁶¹ <http://medrobotics.com/gateway/flex-robotic-system-us/>, 3rd April, 2017

³⁶² <http://www.transenterix.com/surgibot/>, 20th April, 2017

³⁶³ <http://avramedicalrobotics.com/avra-technology.html>, 4th April, 2017

³⁶⁴ http://www.robotdoc.com/professionals_howitworks.html, 3rd April, 2017

³⁶⁵ <https://patients.stryker.com/hip-replacement/procedures/mako-robotic-arm-assisted>, 3rd April, 2017

³⁶⁶ <http://www.smith-nephew.com/professional/microsites/navio/overview/product-overview/>, 3rd April, 2017

³⁶⁷ <http://www.mazorrobotics.com/surgeons/spine-procedures-performed>, 4th April, 2017

³⁶⁸ <http://thinksurgical.com/professionals/professional-home/technologysolution-one>, 4th April, 2017

³⁶⁹ http://www.omnils.com/patients/OMNIBotic_surgery.cfm, 3rd April, 2017

The examples above indicate that surgical robots are usually actually tele-operated devices that are continuously supervised, directed and operated by human surgeons. More autonomous surgical robots appear to be still in the research phase. Historical surgical robots are listed e.g. here³⁷⁰.

³⁷⁰ <http://allaboutroboticsurgery.com/home.html>, 4th April, 2017

4. Estimation of senior citizens needing care

Eurostat publishes annual reviews on “population structure³⁷¹ and ageing” in Europe. The estimation in 2015 showed clearly the increasing number of elderly people (Figure 24).

The population is getting older in most industrialised countries. The largest share of people older than 64 is in Japan (Figure 25, N.N., 2015). Another document from Frost & Sullivan (N.N., 2015B) classifies Japan, Germany, Finland and Greece as “Super Aged Nations” from 2015, Netherlands, France and Sweden from 2020 and Canada and Spain from 2025.

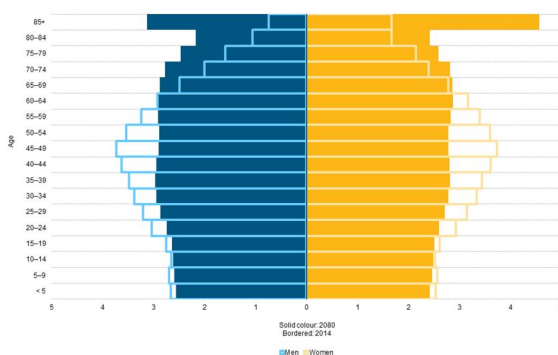


Figure 24 Population pyramids, EU-28, 2014 and 2080 (% of total population), Eurostat, 2015

There are many updated statistics services on population and demography³⁷². Some relevant ones are listed in the table below (Table 4).

Table 4 Statistical services related to population and demography

Name	Org.	Topic
ECHI ³⁷³	EU	European aging indicators
Healthy Life Years ³⁷⁴	EU	"disability-free life expectancy"

³⁷¹ http://ec.europa.eu/eurostat/statistics-explained/index.php/Population_structure_and_ageing, 2nd Aug., 2016

³⁷² <https://en.wikipedia.org/wiki/Demography>, 2nd Aug., 2016

³⁷³ http://ec.europa.eu/health/ageing/indicators/index_en.htm, 5th Aug., 2016

³⁷⁴ http://ec.europa.eu/health/indicators/healthy_life_years/index_en.htm, 5th Aug., 2016

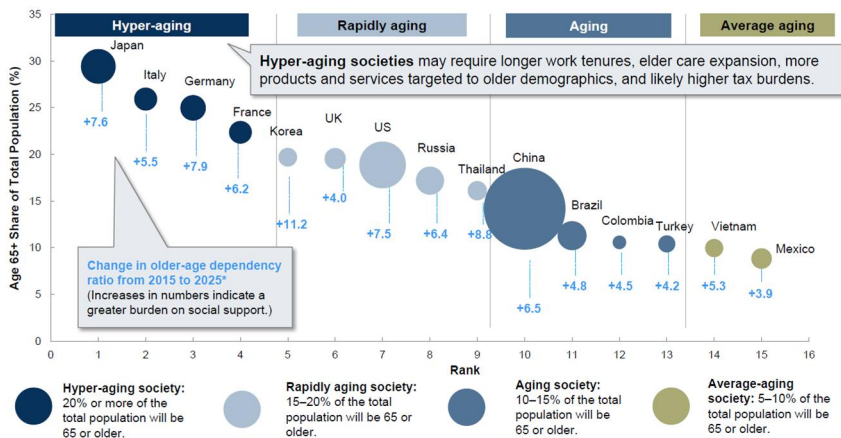


Figure 25 Aging societies globally in 2025 (N.N., 2016C, Copyright: Frost & Sullivan)

Illnesses and health care costs typically concentrate in groups of chronically ill persons. There are clear needs for preventive care. Frost & Sullivan (N.N., 2016B) concluded that:

“In Western Europe, 3 out of 5 people aged over and above 65 have at least two chronic conditions. ... 72% of the healthcare budget is spent on treating chronic diseases and long-term illnesses in various health systems. ... 54% of healthcare costs are dedicated to hospital readmissions and providing care services to frail older people and patients with disability and mental illness. ... Buurtzorg³⁷⁵ Integrated Care Program ...has shown 40% reduction in client cost ... due to promotion of self-care and preventive care to patients.”

Figure 26 below shows an example of how statistics (on *Healthy Life Years*³⁷⁶, HLY) can be utilised. There are also available statistics on *Life Expectancy (LE)* at the age of 65 years, i.e. how long do people on average live after reaching 65 years. – Green (men) and blue (women) lines show at what age persons in some European countries meet severe or moderate health problems, if they were alive at the age of 65 years. Red (women) and violet (men) lines show at what age the same persons typically die. The following conclusions are obvious:

- European people typically die at the same age if they reach 65 years of age, men at age 83 years and women at 86.

³⁷⁵ https://en.wikipedia.org/wiki/Buurtzorg_Nederland, 16th Nov., 2016

³⁷⁶ http://ec.europa.eu/health/indicators/healthy_life_years/index_en.htm, 29th April, 2017

- German and Finnish people are close to the European average in this respect
- Norwegian and Swedish people have typically 5 more healthy years than the European average. This leads to considerable differences in national health costs.

4.1 USA – Attracting market for elderly care

It is well known that US (United States of America) markets are the most difficult but also the most tempting market for products and services that are highly scalable and repeatable. Such markets would also be suitable for Finnish companies that quite often concentrate on smaller niches³⁷⁷. Another option is to sell a company or a specific business to a larger US company continuously searching for new and growing business ideas or well-established business units.

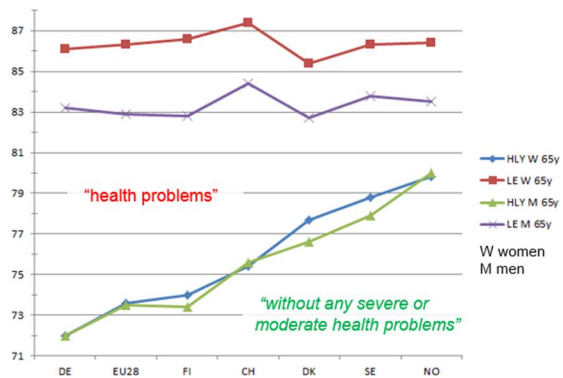


Figure 26 Period between Healthy Life Years (HLY) and Life Expectancy (LE) end at age of 65

McWilliams of BCC Research (2015) has described US Elderly Care Markets well:

*“In 2014, the U.S. home telehealth market ... \$8.2 billion ... 42% of the U.S. tele-medicine market. Growing ... **CAGR of 24%**, the **home telehealth market** has the potential to reach **\$30 billion by 2020**. ... approximately nine million people over the age of 65 in the U.S. needed long-term care in 2014, and by 2020, ... to 12 million. ... **approximately 8 million U.S. individuals received home healthcare from 58,500 providers in 2013**. ... **31,000 assisted living facilities** in the U.S. today, serving more than one million senior citizens”*

Furthermore, McWilliams (2015) estimated that US home healthcare expenditures were 86.8 billion USD in 2014 and will be 129.9 billion in 2020.

³⁷⁷ https://en.wikipedia.org/wiki/Niche_market, 5th Aug., 2016

The traditional health care costs in the USA are high, as health care is to a large extent managed by private companies with profits involved. See the McWilliams (2015B) quote in Section 3.3 on page 47.

Medicare “provides³⁷⁸ health insurance for Americans aged 65 and older who have worked and paid into the system.” **Medicaid**³⁷⁹ “is the largest source of funding for medical and health-related services for people with low income”. These two programmes paid about 81% of US home healthcare costs in 2014, 42.6% and 38.4% correspondingly (McWilliams, 2015). The details and expansion of Medicaid are still under development.

A recent analysis of Lehr of BCC Research (2016) estimated the total **elderly care market** in the US including products, services, housing and assistive technology to **417 billion USD in 2015** and **513 billion in 2020** (Figure 27).

Need	2014	2015	2020	CAGR% 2015-2020
Healthcare*	138,012.0	154,979.0	194,440.0	4.6
Housing**	237,800.0	255,774.0	310,320.0	3.9
Assistive technology	5,741.8	6,207.0	7,958.0	5.1
Total	381,553.8	416,960.0	512,718.0	4.2

*Healthcare includes pharmaceuticals, selected surgical care and selected respiratory therapies.

**Housing includes at-home remodeling, independent living, assisted living, skilled nursing care, home health services and adult day care.

Figure 27 U.S. market for individuals over 65 by type of need (Lehr, 2016) Source: BCC Research, Copyrighted Material, All rights reserved

The widely spread US roadmap on robotics (N.N., 2016D) gives at least one good business opportunity to consider – also outside the USA. This is the rehabilitation of stroke patients. There are currently about 800 000 new strokes in the USA annually. The number is expected to double in 20 years, as the average age of the population in USA increases.

*“**Stroke patients** must engage in intensive rehabilitation to attempt to regain function and minimize permanent disability. However, there is already a **shortage of suitable physical therapists** ... Sensory-motor therapy, in which a human therapist and/or robot physically assists (or resists) a patient during upper or lower extremity movements helps people re-learn how to move. This process is time-consuming and labor-intensive, but **pays large dividends** in terms of patient health care costs and return to productive labor.”* (N.N., 2016D)

³⁷⁸ [https://en.wikipedia.org/wiki/Medicare_\(United_States\)](https://en.wikipedia.org/wiki/Medicare_(United_States)), 3rd Aug., 2016

³⁷⁹ <https://en.wikipedia.org/wiki/Medicaid>, 3rd Aug., 2016

There are already several rehabilitation robots on the market, e.g. InMotion Robots³⁸⁰ by Bionik Labs³⁸¹, Tyromotion³⁸² systems and the ones mentioned in Table 2 on page 7 with the classification “PT” i.e. “Physically therapeutic”. Toyota is also entering the market³⁸³.

4.2 On Finnish elderly care needs

Population projections³⁸⁴ are published at intervals of a few years by Statistics Finland. The last one was based on 2015 estimates during the writing of this document.

The National Institute for Health and Welfare (“THL”) collects health-related data in Finland. THL also estimates³⁸⁵ the percentage of people in Finland that have “*great difficulties in activities of daily living*” and are of age 75 and over. The last published percentage referring to the year 2014 was 25.6%. Combining these two estimate sets, one can estimate the number of elderly persons needing daily assistance. Such an estimate is shown in the Figure 28. It shows over 74 years old males (blue squares), females (red) and the sum of females and males (green triangles) based on population projections in Finland. The number of persons that have “*great difficulties in activities of daily living*” is shown with violet crosses. The estimated number of such persons was about 123 000 in 2015 and 236 700 in 2040. This means that the number of assisted elderly persons will increase about 2.7% on average each year during the period from 2015 to 2040.

The Finnish Ministry of Social Affairs³⁸⁶ and Health has calculated the average annual social and health care costs for each age in Finland. The result is shown in issue 1 of *Nykypäivä*³⁸⁷ in 2016 (on page 22). The costs are about 2 000€ annually for young adults and more than 20 000€ for persons aged 83 and over.

If there is no radical change in methods and infrastructure, the costs and personnel demands will also increase in a corresponding manner. Thus, there is a contradiction to ongoing “SOTE³⁸⁸ discussions” in which savings are one of the main driving forces.

It should be noted that there are also other groups of persons needing daily assistance. Among them are persons handicapped from birth or due to accidents.

³⁸⁰ <http://bionikusa.com/healthcarereform/upper-extremity-rehabilitation>, 4th March, 2017

³⁸¹ <http://bionikusa.com/about-us/>, 4th March, 2017

³⁸² <http://tyromotion.com/en/products>, 4th March, 2017

³⁸³ http://www.roboticstrends.com/article/toyotas_welwalk_robot_brace_stroke_victims, 18th April, 2017

³⁸⁴ http://tilastokeskus.fi/til/vaenn/index_en.html, 27th Sept., 2016

³⁸⁵ <https://www.sotkanet.fi/sotkanet/en/taulukko/?indicator=szY0SQcA®ion=s07MBAA=&year=sy4rtTbS0zUEAA==&gender=t&abs=f&color=f>, 27th Sept., 2016

³⁸⁶ <http://stm.fi/en/frontpage>, 28th Oct., 2016

³⁸⁷ http://grafiikka.nykypaiva.fi/digipaper/digipaper_128131/, 28th Oct., 2016

³⁸⁸ <http://alueuudistus.fi/en/frontpage>, 28th Sept., 2016

Other health-related statistics support the above. For example, the numbers of elderly people with difficulties to move outdoors is periodically estimated³⁸⁹.

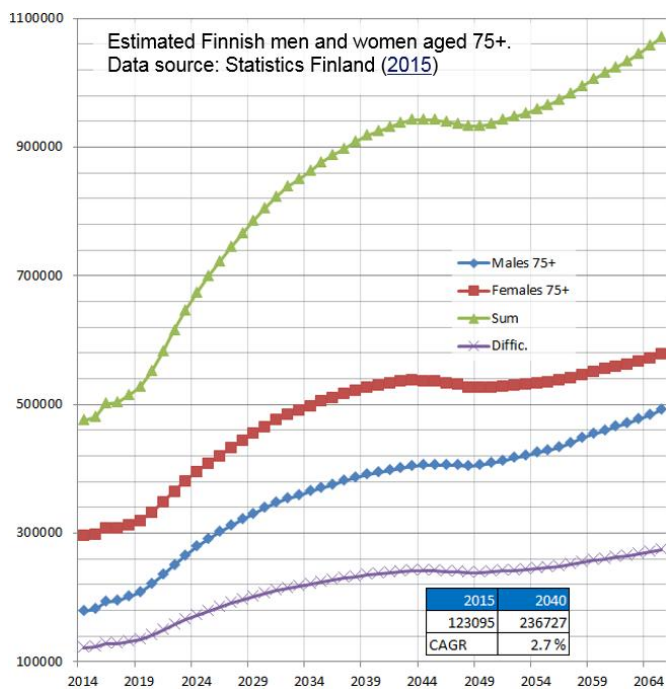


Figure 28 Population projections on persons aged over 74 in Finland and numbers of persons with “great difficulties in activities of daily living”

³⁸⁹ <http://www.findikaattori.fi/fi/64>, 5th June, 2017

5. How to continue?

The following aspects were noted during the writing of this document:

- Care robots appear to be a hot research topic globally and one of the key fields of many governmental initiatives.
- Care-related start-up companies are born and die in large numbers. Numerous different technologies are tried. Big companies outside traditional healthcare are also interested in the topic.
- Robots or robot automation is not the only key to success. The back-office systems supporting robots and their nurse companions in their work should be well functional before robot applications are even tried.
- System design and integrated automation methods should be applied with a holistic approach to home care and institutional care of senior citizens. Robots will only be part of it.
- Care robot and automation applications should be tested with voluntary persons and with good possibilities for individuals to maintain their privacy. When they and other interest groups see nothing but benefits, the positive word-of-mouth marketing will increase the number of people requesting to enter the trials and the potential for developing “well-conceived” care automation operations and services in a standardised manner.
- There are telepresence robots that can move tablets autonomously or via teleoperation in buildings. However, the operation should be possible with an arrangement in which the person moves the tablet themselves or e.g. with a personal wheel chair. In addition, the same user interface should also be available for smartphones. Then the services are available with different price levels and the telepresence robot is not necessary. Thus, cost/service options are needed to accelerate the exploitation.

The following scenarios were underlying in the analysis resulting in this document and were also improved during writing of the document. Such scenarios are most fruitful that are supported and enabled by mass produced equipment and the internet. Robots need supporting automation, data, general user interfaces and

service and software providers in order to be successful. The scenarios may also be utilised simultaneously in parallel or partially.

- **Hospital and dormitory logistics:** Versions of industrial AGV vehicles take care of parcel, e.g. food and laundry logistics in corridors at a “logistics level” allowed for personnel. AGV vehicles pick and deliver items to and from use sites using lifts. Voluntary patients are transferred to and from e.g. laboratory and x-ray with telepresence equipped AGV beds. Logistics are designed in parallel with the design of the buildings.
- **Telepresence, wearables and remote health supervision:** A person learns to use telepresence with relatives. A volunteer is equipped with a suitable selection of wearable systems measuring health-related signals and potentially providing medicine or a cure. An internet-connected device (robot, computer, tablet, smartphone, smart speaker or related) sends data or conclusions to an analysis centre. The analysis software generates alarms and visualises data. Medical personnel utilise telepresence and direct preventive care.
- **Parcel and person logistics for a longer period at home:** Autonomous vehicles transfer parcels (e.g. food, medicines, samples and mail) to homes in rural areas. Autonomous shuttle busses take persons to laboratories and back home.
- **Smart home and bed/chair AGV for the physically disabled:** The AGV telepresence bed, which also transforms to a chair, moves the person around a smart 200-inhabitant home building with service stations and medical care. Telepresence meeting stations, semi-automated spa, restaurants, rehabilitation robots, park routes, and so on.

Much planning and testing work is needed to design the scenario applications so that they will reduce the costs of elderly care. In addition, they may turn out to be the best potential solutions to take care of increasing numbers of elderly citizens.

It appears that there are many needs to increase ROSE to a set of projects which tackles various aspects of elderly care. The Danes appear to have formulated well the scope of the Patient@home²⁸⁸ project. In addition to care robots, it takes care of rehabilitation, home monitoring and clinical tests for the technology developed in the project.

As assistive and care robots should be designed when the hospital or dormitory is designed, governmental health authorities should establish or enable evolution of standards for elderly care automation and robotics. They should be utilised in equally recommended “general offer request and offer exchange e-market for care automation related services, construction and equipment”. Most probably, it is wise to use the HILMA³⁹⁰ as an underlying platform for the service.

³⁹⁰ <https://www.hankintailmoitukset.fi/fi/>, 3rd may, 2017

Rebecca A. Hill summed up the situation nicely in her article³⁹¹ title in “Robotic Trends”:

“Assistive Robots Vital to Future of Elder Care”

³⁹¹

http://www.roboticstrends.com/article/assistive_robots_vital_to_future_of_elder_care/medical, 19th April, 2017

References

- Alwan, M., Rajendran, P., Kell, S., Mack, D., Dalal, S., Wolfe, M., Felder, R. 2006. A smart and passive floor-vibration based fall detector for elderly. In: IEEE Proc. of Int. Conf. on Information and Communication Technologies: From Theory to Applications. P. 1003–1007. (DOI: 10.1109/ICTTA.2006.1684511)
- Bedaf, S., Gelderblom, G.J., De Witte, L. 2015. Overview and categorization of robots supporting independent living of elderly people: What activities do they support and how far have they developed. *Assistive Technology*, 27(2). Pp. 88–100. (DOI: 10.1080/10400435.2014.978916)
- Beedholm, K., Frederiksen, K. Lomborg, K. 2016. What Was (Also) at Stake When a Robot Bathtub Was Implemented in a Danish Elder Center: A Constructivist Secondary Qualitative Analysis. *Qualitative health research*, 26(10). Pp. 1424–1433. (<http://qhr.sagepub.com/content/26/10/1424>, 24th Aug., 2016)
- Cavallo, F., Aquilano, M., Bonaccorsi, M., Limosani, R., Manzi, A., Carrozza, M.C., Dario, P. 2014. Improving domiciliary robotic services by integrating the ASTRO robot in an Aml infrastructure. *Springer Tracts in Advanced Robotics*. Vol. 94. Pp. 267–282. (DOI: 10.1007/978-3-319-02934-4_13)
- Chaudhuri, S., Thompson, H., Demiris, G. 2014. Fall detection devices and their use with older adults: A systematic review. *J. of Geriatric Physical Therapy*, 37(4), pp. 178–196. (DOI: 10.1519/JPT.0b013e3182abe779)
- Clotet, E., Martínez, D., Moreno, J., Tresanchez, M., Palacín, J. 2016. Assistant Personal Robot (APR): Conception and Application of a Tele-Operated Assisted Living Robot. *Sensors (Basel, Switzerland)*, 16(5), 610. (CC BY 4.0, <http://doi.org/10.3390/s16050610>, <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4883301>, 4th, Aug., 2016)
- Dickmann, J., Appenrodt, N., Klappstein, J., Bloecher, H.-L., Muntzinger, M., Sailer, A., Hahn, M., Brenk, C. 2015. Making bertha see even more: Radar contribution. *IEEE Access*, 3, pp. 1233–1247. (DOI: 10.1109/ACCESS.2015.2454533)
- Ermes, M., Pärkkä, J., Mäntyjärvi, J., Korhonen, I. 2008. Detection of daily activities and sports with wearable sensors in controlled and uncontrolled conditions. *IEEE Trans. on Information Tech. in Biomedicine*, 12(1), pp. 20–26. (DOI: 10.1109/TITB.2007.899496)

- Hendrich, N., Bistry, H., Zhang, J. 2015. Architecture and Software Design for a Service Robot in an Elderly-Care Scenario. [J.] Engineering, 2015, 1(1), pp. 27–35. (DOI: 10.15302/J-ENG-2015007, CC BY 4.0)
- Isoaho, P. 2016. Designing a Service/Care robot. Thesis (Bac. of Eng.). Helsinki Metropolia Univ. of Applied Sciences. P. 37. (<http://www.urn.fi/URN:NBN:fi:amk-2016060211654>, 14th Jan., 2017)
- Khosravi, P., Ghapanchi, A.H. 2016. Investigating the effectiveness of technologies applied to assist seniors: A systematic literature review. Int. j. of Medical Informatics, 85(1), pp. 17–26. (<http://dx.doi.org/10.1016/j.ijmedinf.2015.05.014>)
- Laxmi, V. 2017. Medical Devices: Technologies and Global Markets. Wellesley: BCC Research, p. 324. (ISBN 1-62296-410-1, <http://www.bccresearch.com/market-research/healthcare/medical-devices-markets-report-hlc170b.html>, 2nd, April, 2017)
- Lehtinen, H., Kaarmila, P., Blom, M., Kauppi, I., Kerva, J. 2000. Mobile robots evolving in industrial applications. Industry Canada: Proc. of the 31st Int. Symp. on Robotics (ISR 2000), Montreal, Canada, 14–17 May. Pp. 96–101. (ISBN 0-9687044-0-9)
- Lehr, P. 2016. The Elder Care Market: Products and Services. Wellesley: BCC Research, p. 173+26. (ISBN 1-62296-231-1, <http://www.bccresearch.com/market-research/healthcare/elder-care-market-report-hlc062c.html>, 4th, Aug., 2016)
- Mast, M., Burmester, M., Berner, E., Facal, D., Pigini, L., Blasi, L. 2010. Semi-autonomous teleoperated learning in-home service robots for elderly care: A qualitative study on needs and perceptions of elderly people, family caregivers, and professional caregivers. Proc. of the 20th Int. Conf. on Robotics and Mechatronics. Varna, Bulgaria, October 1–6. (URN: urn:nbn:se:liu:diva-106189, [https://www.hdm-stuttgart.de/forschung_transfer/forschungsschwerpunkte/information_experience/publications/Mast%20et%20al.%20\(2010\)%20-%20Service%20Robot%20User%20Needs.pdf](https://www.hdm-stuttgart.de/forschung_transfer/forschungsschwerpunkte/information_experience/publications/Mast%20et%20al.%20(2010)%20-%20Service%20Robot%20User%20Needs.pdf), 24th Feb., 2017)
- Mastorakis, G., Makris, D. 2014. Fall detection system using Kinect's infrared sensor. J. of Real-Time Image Processing. Vol 9, pp. 635–646. (DOI:10.1007/s11554-012-0246-9)
- McWilliams, A. 2015. Technologies for Long-Term Care and Home Healthcare: Global Markets. Wellesley: BCC Research, p. 194+20. (ISBN 1-62296-152-8, <http://www.bccresearch.com/market-research/healthcare/elder-home-healthcare-market-hlc079c.html>, 2nd, Aug., 2016)

- McWilliams, A. 2015B. Medical Automation Technologies, Products and Markets. Wellesley: BCC Research, p. 155. (ISBN 1-62296-078-5, <http://www.bccresearch.com/market-research/healthcare/medical-automation-technology-products-markets-report-hlc066c.html>, 2nd, Aug., 2016)
- McWilliams, A. 2016. Global markets for telemedicine technologies. Wellesley: BCC Research, p. 167. (ISBN 1-62296-296-6, <http://www.bccresearch.com/market-research/healthcare/telemedicine-technologies-global-markets-report-hlc014h.html>, 22nd, July, 2016)
- McWilliams, A. 2016B. Smart Machines: Technologies and Global Markets. Wellesley: BCC Research, p. 156. (ISBN 1-62296-262-1, <http://www.bccresearch.com/market-research/instrumentation-and-sensors/smart-machines-tech-markets-report-ias094b.html>, 22nd, Aug., 2016)
- Moon, Y., Choi, J. 2015. Robotic systems for minimally invasive diagnosis and therapy. Biomedical Engineering: Frontier Research and Converging Technologies. Pp. 463-487. (DOI: 10.1007/978-3-319-21813-7_20)
- Mourujärvi, J., Ruuskanen, A. 2013. Paro Enabling Communication and Interaction Skills of Elderly Person with Dementia (In Finnish: Paro-hyljerobotti mahdollistamassa ikääntyvän muistisairaana ihmisen kommunikaatio- ja vuorovaikutustaitoja). Oulu University of Applied Sciences. P. 48+11. (https://publications.theseus.fi/bitstream/handle/10024/64656/Mourujarvi_Juulia_Ruuskanen_Anna.pdf?sequence=1, 24th Aug., 2016)
- N.N. 2016. 2016 Global Outlook for the Healthcare Industry. Mountain View: Frost & Sullivan. (<http://www.frost.com/prod/servlet/catalog-download.pag?catid=NFF8-01-00-00-00>, 2nd Aug., 2016)
- N.N. 2016B. Role of Mobile Computing Applications in Supporting Integrated Care in Western Europe. Mountain View: Frost & Sullivan. (<http://cds.frost.com/p/166839#!/ppt/c?id=MC3A-01-00-00-00>, 16th Nov., 2016)
- N.N. 2016C. Lifestyle Diseases—Could Wearables be the Solution? Mountain View: Frost & Sullivan. (<http://cds.frost.com/p/166839#!/ppt/c?id=K080-01-00-00-00>, 2nd Aug., 2016)
- N.N. 2016D. A Roadmap for US Robotics – From Internet to Robotics – 2016 Edition. Edited by Argall B. et al. (<http://jacobsschool.ucsd.edu/contextualrobotics/docs/rm3-final-rs.pdf>, 15th Dec., 2016)

- N.N. 2016E. Global Care Assistance and Automation Robots Market, Forecast to 2021 – Robot-based Hospital Automation and Augmented Quality of Care for Elderly and Disabled Offer High-yield, Early-stage Investment Opportunities for First Movers. Mountain View: Frost & Sullivan. (<http://cfs.frost.com/p/166839/#!/ppt/c?id=K0F6-01-00-00-00>, 28th Dec., 2016)
- N.N. 2016F. Strategic Outlook of Global Autonomous Driving Market in 2016. Mountain View: Frost & Sullivan. (<http://cfs.frost.com/p/166839/#!/ppt/c?id=MBD3-01-00-00-00>, 28th Dec., 2016)
- N.N. 2016G. Vision 2025 – The Future of Healthcare. Mountain View: Frost & Sullivan. (<http://www.frost.com/K0EB>, 28th Dec., 2016)
- N.N. 2015B. Major Trends and Attractions in the Global Aged Care Market. Mountain View: Frost & Sullivan. (<http://www.frost.com/prod/servlet/catalog-download.pag?catid=P87F-01-00-00-00>, 2nd Aug., 2016)
- N.N. 2015C. The Human Brain: An Unsaleable Commodity. Mountain View: Frost & Sullivan. (<http://www.frost.com/prod/servlet/catalog-download.pag?catid=9817-00-F0-00-00>, 11th Jan., 2017)
- Oresko, J.J., Jin, Z., Cheng, J., Huang, S., Sun, Y., Duschl, H., Cheng, A.C. 2010. A wearable smartphone-based platform for real-time cardiovascular disease detection via electrocardiogram processing. *IEEE Trans. on Information Tech. in Biomedicine*, 14(3), pp. 734–740. (DOI: 10.1109/TITB.2010.2047865)
- Pearce, A.J., Adair, B., Miller, K., Ozanne, E., Said, C., Santamaria, N., Morris, M.E. 2012. Robotics to enable older adults to remain living at home. *J. of Aging Research*, 2012. (<http://dx.doi.org/10.1155/2012/538169>)
- Ray, C., Mondada, F., Siegart, R. 2008. What do people expect from robots? 2008 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems. IROS 2008. Pp. 3816–3821. (DOI: 10.1109/IROS.2008.4650714)
- Rentschler, A.J., Simpson, R., Cooper, R.A., Boninger, M.L. 2008. Clinical evaluation of Guido robotic walker. *Journal of Rehabilitation Research and Development*, 45(9), pp. 1281–1294. (DOI: 10.1682/JRRD.2007.10.0160)
- Rocon, E., Belda-Lois, J.M., Ruiz, A.F., Manto, M., Moreno, J.C., Pons, J.L. 2007. Design and validation of a rehabilitation robotic exoskeleton for tremor assessment and suppression. *IEEE Transactions on Neural Systems and*

- Rehabilitation Engineering, 15(3), pp. 367–378. (DOI: 10.1109/TNSRE.2007.903917)
- Sharkey, A., Sharkey, N. 2012. Granny and the robots: Ethical issues in robot care for the elderly. *Ethics and Information Technology*, 14(1), 27–40. (doi:10.1007/s10676-010-9234-6)
- Singh, S. 2015. Critical reasons for crashes investigated in the National Motor Vehicle Crash Causation Survey. Washington, DC: National Highway Traffic Safety Administration. Report No. DOT HS 812 115, <https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115>, 12th Jan., 2017).
- Tang, D., Yusuf, B., Botzheim, J., Kubota, N., Chan, C.S. 2015. A novel multimodal communication framework using robot partner for aging population. *Expert Systems with Applications*, 42(9), pp. 4540–4555. (DOI: 10.1016/j.eswa.2015.01.016, <http://web.fsktm.um.edu.my/~cschan/doc/TMJ.pdf>, 29th Aug., 2016)
- Tsuji, T., Mozos, O.M., Chae, H., Pyo, Y., Kusaka, K., Hasegawa, T., Morooka, K., Kurazume, R. 2015. An informationally structured room for robotic assistance. *Sensors (Switzerland)*, 15(4), pp. 9438–9465. (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4431256/>, 9th Aug., 2016)
- Tulonen, T. 2016. Robotit ikääntyneiden hoidossa – toiveet ja huolet. (Robots in elderly care – desires and worries). Tampere Univ. Master's Thesis. P. 51 + 3. (<http://tampub.uta.fi/handle/10024/99646>, 24th Feb., 2017)
- Wadhwa, H.S. 2016. Patient Monitoring Devices: Global Markets. Wellesley: BCC Research, p. 173. (ISBN 1-62296-314-8, <https://www.bccresearch.com/market-research/healthcare/patient-monitoring-devices-markets-report-hlc038e.html>, 20th April, 2017)
- Wilson, J. 2016. Robotics: Technologies and Global Markets. Wellesley: BCC Research, p. 250. (ISBN 1-62296-320-2, <http://www.bccresearch.com/market-research/engineering/robotics-technologies-markets-report-eng001e.html>, 2nd, Aug., 2016)
- Vildjiounaite, E., Mäkelä, S.-M., Järvinen, S., Keränen, T., Kyllönen, V. 2014. Predicting consumers' locations in dynamic environments via 3d sensor-based tracking, *Proc. of 2014 8th Int. Conf. on Next Generation Mobile Applications, Services and Technologies, NGMAST 2014*. Pp. 100–105. (DOI: 10.1109/NGMAST.2014.11)
- Virtanen, A., Koskinen, S., Peussa, P. 2001. Navigation system using natural landmarks. *FSR2001. 3rd Int. Conf. on Field and Service Robotics*. Espoo,

11–13 June 2001. Helsinki: Finnish Society of Automation. Helsinki. (ISBN 952-5183-13-0)

Title	Application of novel industrial scale robot automation in elderly care
Author(s)	Hannu Lehtinen
Abstract	<p>The potential of automation and robots for elderly care is reviewed. Robot automation for widespread application must be well integrated into societal and other automated systems and services, including e.g. task planning, order/assignment generation and invoicing. A large number of applications and sub-service/component providers will decrease the costs, which will speed up applicability further - often with precipitous growth in numbers. Related estimates and predictions in the literature are reviewed. A few robot applications suitable for Finnish experience and industrial structure are studied in greater detail – e.g. who will develop them, and where, why and what is the estimated demand.</p> <p>The vision of the following scenarios – used simultaneously in parallel or partially – has directed the work resulting in this paper: (1) Telepresence, wearables and remote health supervision, (2) Parcel and person logistics for extended home living, (3) Hospital and dormitory logistics and (4) Smart home and bed/chair AGV for the physically disabled. The scenario (1) is assumed especially to decrease the costs of health care when massively exploited, and to make health care more preventive, and the scenario (4) to improve the life quality of handicapped persons.</p>
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Nimeke	Teollisen mittakaavan robottiteknologioiden soveltaminen vanhusten hoivaan
Tekijä(t)	Hannu Lehtinen
Tiivistelmä	<p>Raportissa kuvataan, miten automaatiota ja robotteja on hyödynnetty ja aiottu hyödyntää vanhusten hoivassa. Laajalti hyödynnettävissä olevan automaation on oltava kytketty ympäröivään yhteiskuntaan, sen automaatiojärjestelmiin sekä palveluihin, kuten palvelutuotannon ohjaukseen, palveluiden tilausjärjestelmään ja laskutukseen. Suuri sovellusten ja vaihtoehtoisten osajärjestelmien/ osapalveluiden määrä vähentää kustannuksia. Tämä puolestaan lisää sovellettavuutta, mutta nostaa kasvuprosentit suuriksi, jopa vyörymäisiksi. Aiheen kasvuennustuksia on kerätty kirjallisuudesta. Muutamia suomalaisille yrityksille ja kokemuksille sopivia hoiva-automaatiosovelluksia on tarkasteltu lähemmin – esimerkiksi kuka voisi kehittää niitä, missä, miksi ja mikä on arvioitu kysyntä.</p> <p>Seuraavia skenaarioita on käytetty työn pohjana ja niitä on täsmennetty työn aikana. Skenaarioita voidaan käyttää osittain tai yhdistelminä: (1) Etäläsnäolo, puettavat mittalaitteet ja terveydentilan automaattinen tarkkailu, (2) Automaattinen ruoka- ja tavaralogistiikka pidentämään kotona asumista, (3) Automaattinen sairaala- ja palvelutalologistiikka, (4) Älykäs koti ja liikkuva vuode/tuoli liikerajoitteisille. Skenaario (1) laajalti sovellettuna voi vähentää huomattavasti sote-kustannuksia, sillä se siirtää painopistettä ennakoiwaan terveydenhoitoon, ja skenaario (4) voi parantaa merkittävästi elämänlaatua.</p>
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Application of novel industrial scale robot automation in elderly care

Elderly patients in institutional care are fragile. How can robots even be considered to help nurses in varying care tasks where friendliness and the human touch are often required? It is wise to let robots perform tasks which they are good at, and particularly to take care of repetitive tasks. Embedded automation supporting robots often provides better results than the use of a robot only. For example, robots open doors poorly, but automated doors are standard equipment for hospitals and dormitories and are applicable for homes. Logistics are suitable for industrial vehicles in buildings and for autonomous vehicles outdoors. Measuring the health and condition of any person would assist preventive healthcare, which is well known to reduce the overall costs of healthcare.

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