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Newsletter #8 RA2

Date: 12th of June, 2019

This newsletter is published prior to each workshop of SFI Manufacturing. The aim is to keep the community up to date with the current research that is being carried out within and related to the SFI. This issue of the newsletter is focused on the research and achievements from the area RA2 - Robust and Flexible Automation.

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sfi Centre for Research-based Innovation

The Research Council of Norway

SFI Manufacturing

A cross-disciplinary centre for research based innovation for competitive high value manufacturing in Norway

About the research area

The research area Flexible and Robust Automation concerns the novel technologies and methodologies within automation to support innovation processes and advanced work systems in the manufacturing industries.

Novel automation technologies and methodologies, and smart integration of these, open new ways to use automation and robotics in manufacturing systems. However, several research challenges still need to be addressed to release the potential for innovation. Within this research area we focus on generic challenges identified from a mapping at the industrial partners conducted in the timeframe 2016-18. Some examples are bin-picking, safe and efficient motion planning in dynamic environments, "batch size one" robotic assembly, robotic flexibility in additive manufacturing, and effective and safe development of robotic assembly processes. Several of these challenges also link to the other research areas within the SFI.

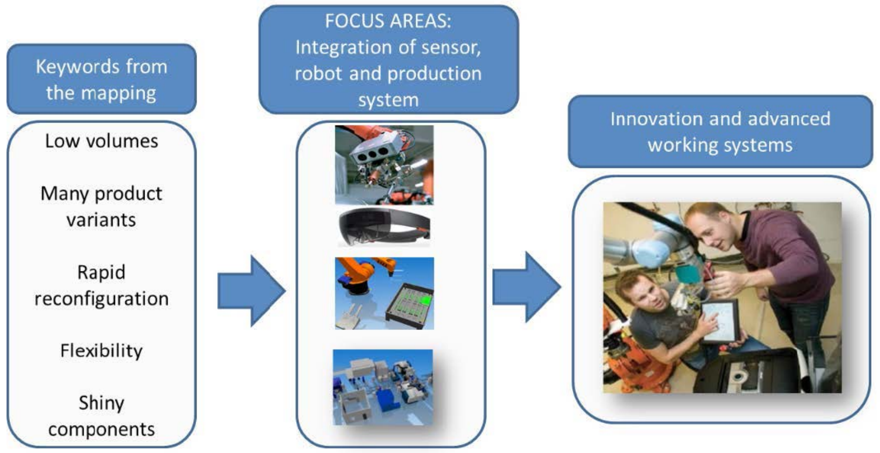

Figure 1. Overall objectives of the research area.

In this newsletter some highlights from the research conducted in 2018 are briefly described. The related results and innovation potentials will also be presented during the upcoming workshop in Bergen. In addition, relevant projects that are either direct spin-off's or thematically relevant that involve one or several of the SFI partners are presented.

International acknowledgement

SFI Manufacturing's research has yet again been internationally acknowledged. The paper "Bin Picking of Reflective Steel Parts using a Dual-Resolution Convolutional Neural Network Trained in Simulated Environment" received T. J. Tarn Best Paper in Robotics award at the IEEE International Conference on Robotics and Biomimetics, Kuala Lumpur, Malaysia, December 2018.

Figure 2. Jonathan S. Dyrstad receiving T. J. Tarn Best Paper in Robotics awards at the IEEE International Conference on Robotics and Biomimetics.

Furthermore, Mathias Hauan Arbo defended his thesis entitled "On Robotic Assembly and Optimization-Based Control of Industrial Manipulators" the 24th of April 2019. The topic of the trial lecture, given two weeks in advance of the defense, was "Conformal geometric algebra: application to robotics". The committee appointed to evaluate his thesis, trial lecture and defense was Professor Anders Robertsson (Lund Universitet), Associate Professor Lucia Pallottino (University of Pisa) and Professor Kristin Y. Pettersen (NTNU). Robertsson and Pallottino evaluated the thesis to be equivalent of a thesis of "very high quality" in their respective home institutions.

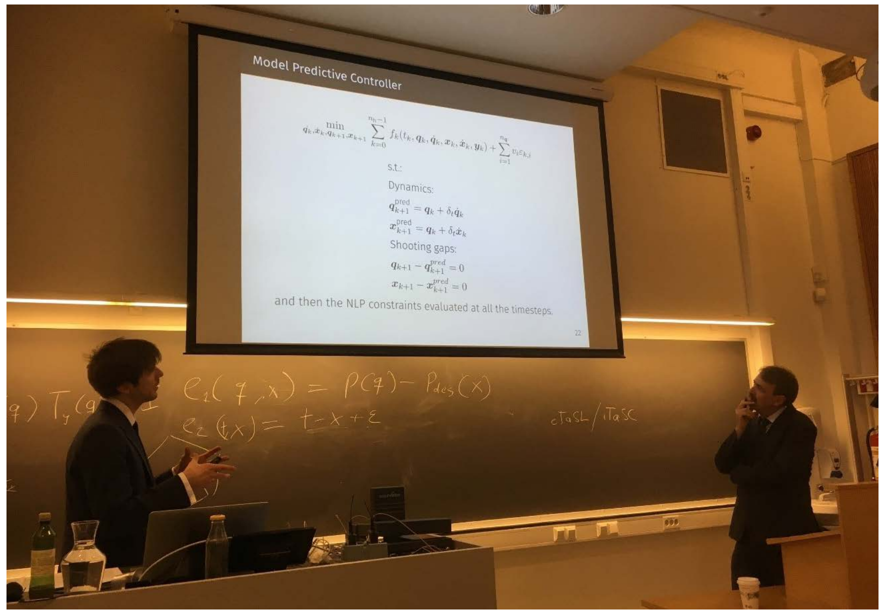

Figure 3. PhD Mathias H. Arbo (left) was the first PhD-student of SFI Manufacturing to defend his thesis. Here seen in discussion with evaluation committee member Professor Anders Robertsson (right).

Research and PhD activities

Vision-based trajectory generation

Manipulator arms are often used for tasks where the same movement is repeated over and over. In the case of bin-picking, the object position randomness requires on-the-fly calculation of new manipulator arm motions for every new object. One of the challenges is how to ensure that the robot can grasp the object without colliding with itself or the environment.

An important feature of our bin-picking set-up has been modularity. This has allowed us to test various motion planners, such as those provided by the MoveIt Motion Planning Framework (https://moveit.ros.org/), but also SEAMLESS, a solution developed in-house at SINTEF through a strategic project. Both approaches use 3D sensing, and the focus of this year has been to integrate information from both a Kinect and Zivid sensor, with the aim of sensing the environment and calculate safe and efficient manipulator arm motions. Although the main purpose of the Zivid sensor is to find suitable grasps, it is instrumental to also use the sensor information to avoid collisions with other parts in the bin and the bin itself. Contact operations are still challenging in an unstructured environment, since objects to be grasped are close to objects that need to be avoided.

When the sensor is attached to the robotic arm performing the grasping, additional constraints on how the manipulator can move whilst avoiding self-collisions and collisions with the bin or other parts of the environment is imposed. With this issue in mind, master student Irja Gravdahl, has investigated what placement of the bin, and which grasps are favourable for reaching with the manipulator arm. Through extensive off-line simulations, statistics can be made for which type of grasps that are easily reachable by the robot, and this information can be used in real-time to make a prioritization of the grasps.

Small-scale Intelligent Manufacturing

Small-scale Intelligent Manufacturing System (SIMS) is an emerging concept. In order to survive in today's rapidly changing market, SIMS is of paramount importance for improving and enhancing the competitiveness and sustainability of manufacturers, especially small and medium-sized ones. SIMS aims at incorporating state-of-the-art technologies with leading edge management methods for achieving continuous improvement on flexibility, reliability, productivity and sustainability of manufacturing systems in order to provide customers with highly customized products at a reasonable price and with rapid delivery.

Using the term "intelligent" related to manufacturing, different levels can be distinguished (from low intelligence to high intelligence):

- Control level: The technologies, e.g. computer numeric controlling, the programmable logic controlling, and probability statistics analysis etc., are used for replacing the labour force and optimizing the production efficiency
- Integration level: Internet of Things and Cyber Physical Systems technology are going to be applied in manufacturing based on the control level technologies, generating the digital manufacturing environment and networks. It does not only connect the hardware but also builds the communication between the controlling systems. The data is collected from sensors, machines, production lines, or manufacturing controlling and management systems, and it is also received from outside of the factory, such as the customer feedback and the supply chain. On this level more valuable information is discovered, which helps people improve manufacturing.
- Intelligence level: Manufacturing uses data or information obtained from the integration level to create the plan and make decisions by intelligent technologies, such as advanced data mining and big data analysis. In addition, the intelligent manufacturing system can self-awareness, self-optimization, self-configuration, etc., which are the concepts of Industry 4.0. Applications of this level tend to be the implementation of Industry 4.0.

Small-scale Intelligent Manufacturing Systems are currently mostly on the control level, and the intelligence level has been unachievable so far. SIMS could be defined as a type of manufacturing system that employs few workers, typically uses small volume and batch sizes, has high product variability and tends to be responsive and competitive applying advanced technology and automation (e.g. industrial robots, hybrid CNC machines, 3D printers, and complex Internet-based integrated communication systems).

PhD progress reports

Mathias Arbo – Robotic assembly with CAD information: Ontology for simple robot programming

In the previous workshop, two system architectures for CAD-Based robotic assembly were presented: The architecture by SINTEF Manufacturing (Koprod) that focuses on flexible robot programming through annotation of CAD models and transparent behavior through digital twin technology, and the constraint-based robot programming architecture by Arbo et al. that focuses on high-level task annotation and generating both assembly skills and parameters. The Koprod project is a higher TRL approach, aiming to rapidly simplify robot programming, whereas the researched architecture is a lower TRL approach, aiming to explore new robust robot programming methods with the hope that they may later serve as building blocks for higher TRL systems. This section presents the lower TRL exploration, for more information on Koprod, see the "Relevant Projects" section.

One of the biggest hurdles going from high-level task annotation to executable robot skills is the systematic grounding of what we say should happen to what we want to happen. In the previous work, annotated assembly tasks were abstract concepts such as "place", "insert", and "screw". In the current iteration, we explore the usage of CAD constraints which define how features on parts "fit" together geometrically, to more concretely define the annotated assembly tasks. These constraints are available in most CAD software, and therefore give an intuitive user-interface for people inexperienced with robotics. To perform the grounding from task annotation to skill execution, an ontology was defined for both extracting relevant information from a CAD design, and for reasoning on this information. The ontology is like a web of relations, you can ask it whether a thing is true, whether A is connected to B, and by building a set of rules, you can figure out whether the constraints defined in a task should be executed by a particular robot skill. The work was also extended with another assembly example by courtesy of Mjøs Metallvarefabrikk. We are currently looking for more complicated assembly scenarios, and any and all suggestions are welcome.

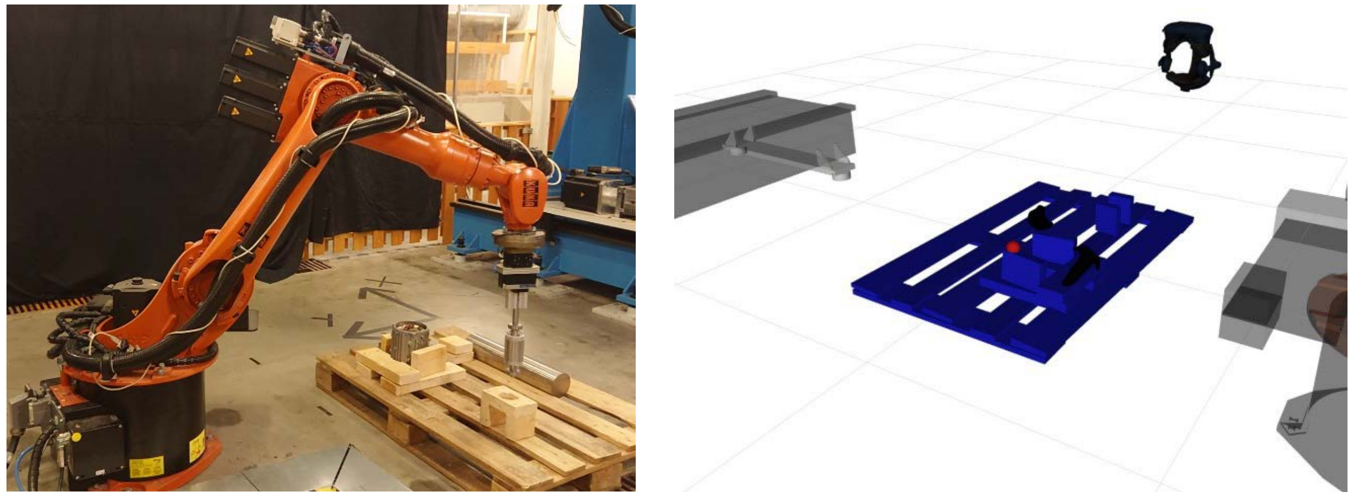

Figure 4a. KR16-2 assembling an electromotor by Mjøs Metallvarefabrikk, programmed with constraint-based skills. Figure 4b. A virtual model of the assembly scenario and its collidable objects, rapidly created with the HTC Vive.

To be able to automatically generate robot skills, we must know where both the parts and the robot are in space. This is often done through either meticulous measurements, by using a vision system, or by moving the robot to all relevant locations and recording them. We have also explored using an HTC Vive tracker for rapid robot cell calibration. Morten Andre Astad shows in his master thesis that the Vive has measurement noise in the range of millimeters, but due to software limitations the system generally has an error of about a centimeter. This makes it useful for rough positioning of parts and obstacles, which can lower the slow approach time used when an industrial robot calibrates its robot cell.

Linn Danielsen Evjemo – Wire Arc Additive Manufacturing

One way of enabling additive manufacturing (AM) in a large workspace and on a large scale, is to use a robot manipulator to deposit material along a pre-designed path. Most of the flexibility for the shape and form of the final product that is offered by traditional AM methods could be kept, or even improved. Overhangs, regions of material built over empty space, without support structures to hold them up, are one of the most basic limitations for traditional AM methods. Because traditional AM methods add material layer by layer either top-down or bottom-up, building structures with overhangs requires that additional support structures are built, and then removed in post-processing. Using the full flexibility of a robot manipulator could allow us to bypass this and build overhangs directly. AM by robot manipulator could be done with metal using welding equipment, or by extruding some other, fast-curing material. Apart from some initial experiments, my work has focused on wire arc additive manufacturing (WAAM), combining a robot manipulator with welding equipment to deposit metal.

This work has in large part been done in collaboration with SINTEF Industry, and the focus has been on cold metal transfer (CMT) welding, though parts of the experiments have used pulsed-MIG welding as well. Both aluminium and the nickel-based alloy Inconel625 have been used to map how material properties affect the resulting build. In the preliminary WAAM experiments the aim was to map some of the challenges we face when trying to do large-scale AM in metal, such as problems related to intersections, or deformations due to heat development during continuous material deposition. Some of these results will be presented at the IFAC conference on Intelligent Control and Automation Sciences in Belfast in August 2019. The structures were built with a fixed, vertical orientation of the welding gun, not using the flexibility offered by the robot's many degrees of freedom.

Figure 5a. Robot cell at SINTEF Industry with ABB robot manipulator and Fronius welding equipment. Figure 5b. Box structures and «Chinese knot» built with fixed orientation of welding gun, mapping challenges related to corners and intersections. Figure 5c. Cup structure built using set-based control to allow for 6° slack in orientation of welding gun.

In the latest experiments, I have worked together with postdoctoral researcher Signe Moe to include set-based theory in the process. This enables us to set a slack limit for the orientation of the tip of the welding gun, allowing it to vary slightly from the reference, which can help make the robot's movements smoother. So far, set-based methods combined with WAAM have only been tested for a simple cup structure with no overhang, as shown to the right. Experiments utilizing the full flexibility of the robot to build more complex structures with overhangs are next on the agenda.

Relevant projects

The SmartChain project at a glance

2017 - 2020
Partners: Kongsberg Maritime Subsea, Norautron, Oswo, Virinco, SINTEF Digital, SINTEF Manufacturing
Contact person at SINTEF Manufacturing: Per Aage Nyen, per.a.nyen@sintef.no

Kongsberg Maritime Subsea (KMS) is a world leading producer of systems for subsea acoustics and maritime robotics for navigation and mapping. In 2017, KMS launched an innovation project (IPN), SmartChain, to meet the challenges arising from increased competition on the world market, in general, and in the functional lower end segment of the product range, in particular. One major enabling factor in this is to achieve a higher degree of automation in manufacturing through digitalization and deployment of Industry 4.0 principles in a refurbished production system.

Holonic manufacturing systems
During the first year of SmartChain, an extensive mapping activity has been carried out in the current production system, in order to reveal the production processes with the greatest potentials for automation and to get a deeper understanding of the dynamics of the production system as it works today. By this insight, a strategy has been defined for evolving the production system into the scope of Industry 4.0. One element in this strategy is to introduce distributed, autonomous control on operational level in the production. The prototype implementation of the PROSA architecture for holonic manufacturing systems (HolMS) developed by SINTEF, was conceptually adopted by KMS for industrialization. HolMS relies heavily on digital interconnectivity and a high degree of automation to reach its full potential. The strategy for introducing HolMS is to:

- Identify a segment of the production system with well-defined interfaces to both upstream and downstream processes
- Replicate this segment in a laboratory environment, introduce new digitalized production equipment
- Establish a communication network in which HolMS can gather information in near real-time
- Calculate optimal decisions in any momentary state of the system

The motivation for this strategy is based on gradual and stepwise introduction of new technology. Basically, HolMS seeks the best decisions for physical routing of parts between production resources, given a particular state of its control area.

New and automated moulding line
The production segment selected for introducing HolMS is a moulding department where ceramic elements are coated in composite materials. In addition to have the required well-defined interfaces, all operations in this department are carried out manually today. KMS has the intention of procuring automated moulding machines which in itself will increase the level of automation. It is also the intention to robotize the machine tending of these moulding machines which will rise the automation level even higher. Altogether, the new moulding line will be fully automated and supervised by one operator. As mentioned above, a stripped-down version of this new moulding line will be set up in a laboratory configuration. This configuration will serve as a platform for experimenting with the new moulding technology and for customization of a HolMS based control. This work is scheduled for start-up in 2019.

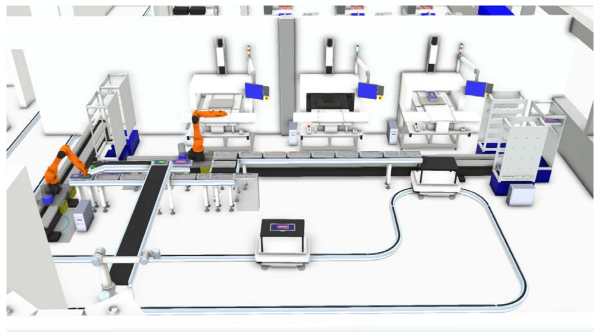

Figure 6. Simulation of the new moulding line.

Koprod – Competitive manufacturing of complex products and a high number of variants

2017 - 2020
Partners: Mjøs Metallvarefabrikk, Sandvik Teeness, Tysse Mekaniske Verksted, Zivid Labs, SINTEF Digital, SINTEF Manufacturing
Contact person at SINTEF Manufacturing: Pål Ystgaard, pal.ystgaard@sintef.no

In the Koprod project, the participating companies have great opportunities within cost-sensitive markets, where future competitiveness depends on increased automation of small and medium volume production with a large range of products. Process mapping has been carried out to be able to select cases that are beneficial for all companies, to develop demonstrators that may include products from each of the companies, and to make recommendations to the research work. All three companies have challenges with manual product assembly.

Intuitive and robust robot programming
One of the main activities in the project is to develop an intuitive and robust robot programming method giving faster change-over and adjustment on manufacturing processes, without the need for robot expertise. The development of solutions for simple, adaptive programming makes the operators less dependent on advanced programming skills when minor changes are made in products or processes. Developing an architecture of the robot programming system was the first part of the research development. Furthermore, an AR model was developed demonstrating the new proposed assembly process. Then, in parallel with the AR-model, a lab-demo showed the process demonstrating calibration and measurements of fixtures and parts and assembly of the selected parts.

Figure 7. Test set-up in the fist laboratory demo in Koprod.

Utilize geometric information
The project's approach, intuitive and fast programming of robotic assembly processes, has been to utilize geometric information already contained in geometric models, as they are represented in a commercial CAD system. By creating CAD assemblies such as the robotic cell before the assembly process starts, the assembled product, and parts mounted in the gripper, the system gets the information it needs to automatically generate a basic assembly sequence. By also adding extra geometric features to the CAD files, such as coordinating frames, points and lines, it is possible to program extra tasks, such as measurement of the accurate position of an assembly fixture with a measurement probe. A prototype of the programming method was demonstrated on an assembly consisting of 6 parts requiring both measurement of initial positions of elements in the assembly cell, insertion with tight tolerances using sensor-based motion, and tightening of bolts. This demonstration also included the use of augmented reality, where virtual tools were mounted on the physical robot, thus letting the operator see the physical movement of the robot without risk of collisions.

A significant challenge in the project is to find ways to handle variations in setups of robotic cells and required assembly tasks, without making the system inaccessible to the less experienced user. Variations include different robot brands, cooperating robots, workpiece manipulators, different sensors, special approach paths, speed and acceleration requirements and so on. This is ongoing work, and we will investigate possibilities both within the CAD system, and with adding extra interfaces to easily add more information about both the cell equipment and the assembly tasks.

CPS Plant – Cyber Physical System Plant Perspective

2017 - 2021
Partners: NTNU, MTP, NAPIC, SINTEF Digital, SINTEF Manufacturing
Contact person at SINTEF Manufacturing: Odd Myklebust, odd.myklebust@sintef.no

The knowledge project CPS Plant is looking at Industry 4.0 as an application for all kind of industries. It has been accepted as a digital strategy for several countries, and by use of Cyber Physical Systems (CPS) and embedded software, it is possible to integrate production systems and equipment, as well as product and processes in buildings, transport & logistics and medical care. CPS Plant cooperates with Hydro, Hycast and Benteler for showing demonstrator cases where cyber physical systems, IoT, zero defect and artificial intelligence can be used as main key openers for correcting and/or improving processes or products in the aluminium value chain.

The last year, we have been working on a framework and in a first face identified 3 main cases. In one of the products we are using data collection, statistical analysis and SPC (statistical process control), and are continuing with a test pilot where different sensors can give more and structured data to improve the specific product. In other cases, the focus will be on process improvement (operators and the shop floor). Implementation of a value chain perspective and learning systems around sensor selection and solutions are also focus areas. The project will bring case descriptions, implementations, methods and methodologies for solutions.

Horizon2020 QUALITY – Digital Manufacturing Platforms for Connected Smart Factories

QU4LITY

2019 - 2021
Research partners: Franhofer institutes IAO, ISST, IPA, IGD, TNO Netherlands, EPFL Switzerland, TU in Dortmund and Braunschweig Germany, Politecnico de Milano, VTT Finland, Jozef Stefan Institute Slovenia, EIT Digital and Research and Education Laboratory in Information Technologies Greece
Contact person at SINTEF Manufacturing: Odd Myklebust, odd.myklebust@sintef.no

QU4LITY, an EU project in the Horizon 2020 program, is about autonomous quality platforms for Zero Defect Manufacturing. The platform builds on an existing ecosystem of 45 partners, with 14 lighthouse pilots in 7 sectors. Among the companies are Philips, Whirlpool, Continental, Siemens, Visual Components, Airbus, Kollektor, Fagor, GF, Thyssenkrup, Modragon and Danobat.

The project will demonstrate, in a realistic and measurable way, an open, certifiable and highly standardised platform. The platform should be SME-friendly, transformative and data-driven, with visions of Zero Defect Manufacturing (ZDM) in product and service modeling. The project will promote new digital business models, such as performance-based and product-service services, through an open platform and ecosystem. SINTEF Manufacturing's role as scientific manager with Odd Myklebust and responsibility for at least two out of the pilots, project manager: Ragnhild Eleftheriadis.

ROMO – Robotics for Moving Objects

2018 - 2021
Partners: Zivid, Tronrud Engineering, Flokk, St. Olavs Hospital, NAV, Orkdal kommune, NTNU, SINTEF Digital
Contact person at SINTEF Digital: Esten Ingar Grøtli, esteningar.grotli@sintef.no

Main objective: Development of methods and tools that will: 1) enable online estimation and identification of moving objects, and 2) support robot interaction and manipulation of such objects in real time.
Expected results: There are two use-cases where the anticipated impact is significant: 1) Manufacturing: Automatic loading/unloading of trolleys from overhead conveyors. This is a labour intensive task, and can for instance lead to strain injuries. Automation could therefore lead to reduced labour cost and/or improved health and safety. 2) Health: Automatic ultrasound examinations: Ultrasound is a common image modality, in the sense that many different examinations can be done with ultrasound, and several patient groups can benefit from this. However, the examination requires high competence. If the process can be automated this would likely mean shorter queues, and more geographically distributed examinations.

FORNY project RoboGlass – Smart eyes and glasses for our blind friends, the robots

2017 - 2019
Partners: Denso, SINTEF TTO, SINTEF Digital
Contact person at SINTEF Digital: Esten Ingar Grøtli, esteningar.grotli@sintef.no

Main objective: The main objective is to develop an integrated hardware and software product that provides an optimal solution to the global path planning problem for robotic manipulators with deterministic run-time and fast re-planning. Status: A "return-to-origin" function was demonstrated at the International Robotics Exhibition in 2017 using a robot from the Japanese manufacturer Denso Wave. If an unforeseen event causes the robot to interrupt its actions, it must return to its "home position" before it can start up again. According to Denso Wave this is a challenging task that can take a long time to implement. During the four days of the exhibition, about 40,000 people visited the Denso stand. The background for the collaboration with Denso Wave and participation at the exhibition was a YouTube video published a couple of years ago as a part of a strategic project at SINTEF called SEAMLESS. The video shows a robot constantly avoiding colliding with people who are trying to obstruct it, and planning a new way to reach its objective. Denso Wave found it so impressive that they wanted to start a collaboration. Expected results: The long-term commercial goal of this FORNY-project is a startup company. The company will market, manufacture and sell a patented product - RoboGlass - for robot suppliers and robot systems integrators.

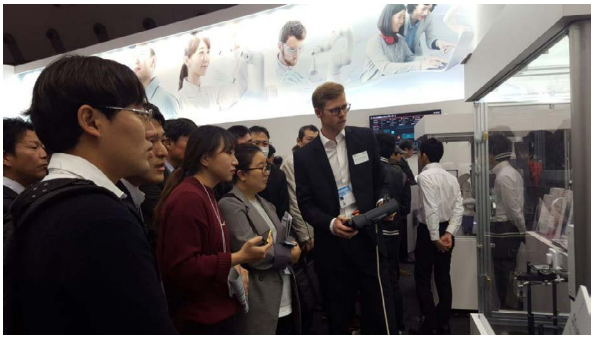

Figure 8. SINTEF's Øystein Hov Holhjem demonstrating the robot. Our collaborative robots, also known as "cobots", attracted a lot of interest.

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