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Newsletter #6 RA2

Date: 17th of October, 2018

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, in order to support innovation processes and advanced work systems in the Norwegian manufacturing industry.

Novel automation technologies and methodologies, and smart integration of those, 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 are focussing on generic challenges based on a mapping among the industrial partners conducted in 2016 and 2017. 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 SFI Manufacturing.

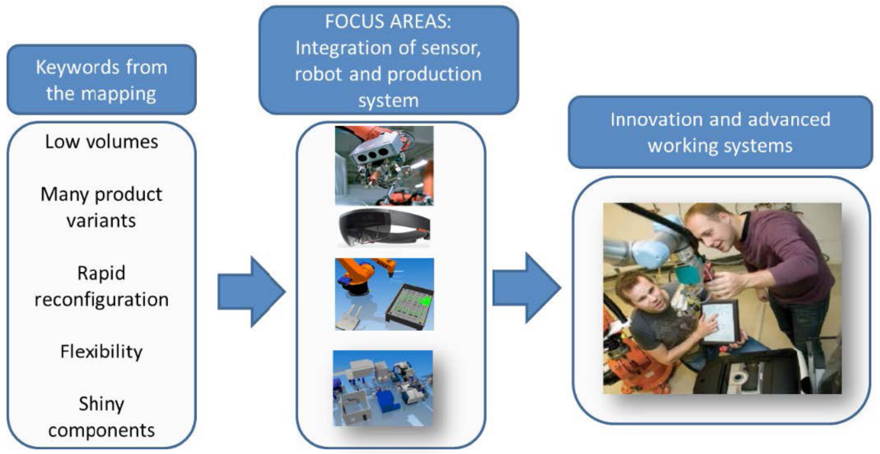


Figure 1. Overall objectives of the research area.

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 Horten. In addition, relevant projects that are either direct spin-off's, or thematically relevant and involving one or more of the SFI partners, are presented.

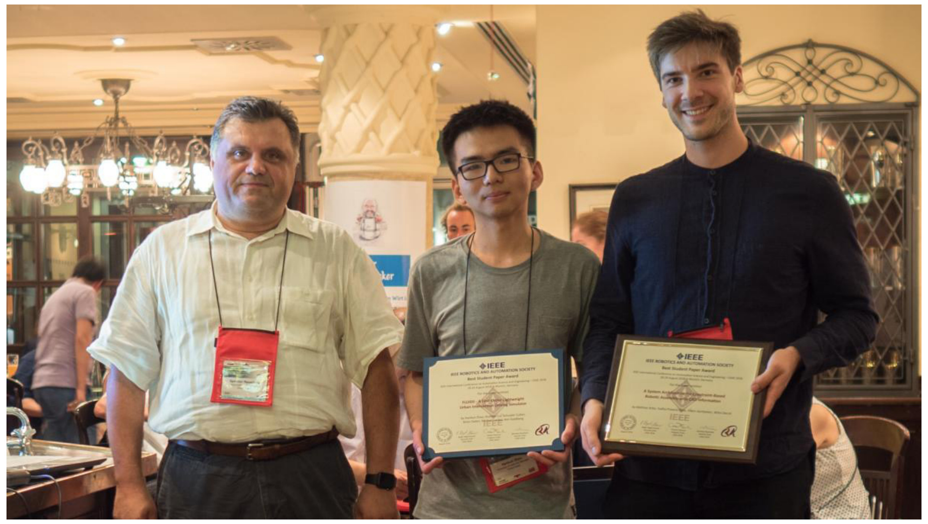


Figure 2. SFI Manufacturing's research is also internationally acknowledged: PhD candidate Mathias Arbo wrote an article which received the "best student paper award" at the EEE International Conference on Automation Science and Engineering (CASE) in Munich, Germany, August 2018. Photo: CASE

Results from research and PhD-activities

Automatic grasping using deep learning

The bin-picking problem is considered one of the core problems in computer vision and robotics. The goal is to use information from one or more sensors in order to pick up objects with random poses in a bin using a robot manipulator arm. In this project we are looking at a particularly challenging use-case: Picking shiny, highly reflective steel objects of different sizes and shapes, without knowledge of the CAD-model. Our proposed solution can roughly be characterized by the following modules: 1) use a deep neural network to suggest feasible grasps from point clouds, and 2) calculate safe and efficient paths for the manipulator arm to reach and grasp the object.

Feasible grasps using deep neural network

One of the long-term goals of our research area is to create a generic system for grasping all types of objects in cluttered scenes. As a step towards this goal, we have developed a system for robot grasping using deep learning. Deep learning algorithms can learn features and tasks directly from images, and can automatically extract high-level, complex abstractions from images. Instead of learning a traditional machine vision system each new object it should handle, a deep learning algorithm can be trained for handling a large spectre of objects and objects in cluttered scenes. These strengths make deep learning an important tool to achieve a more generic system for grasping.

Deep learning models require a huge amount of data in order to create a good model. We have therefore developed a simulation tool that produces simulated data that can be used for the first phase of training. As a 3D camera based on projection of structured light will be used in the physical set-up, the simulator must generate realistic looking depth images with noise resulting from the reflectiveness of the steel parts. This approach of using virtual data reduces the total number of experimental grasps needed for training and save time.

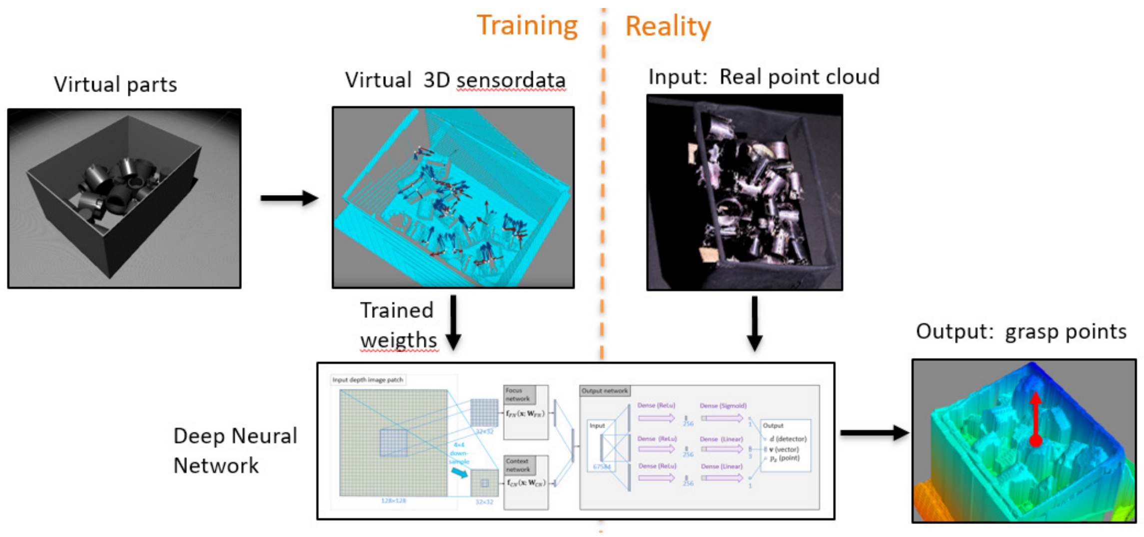


Figure 3. The deep neural network is trained using virtual 3D sensor data.

Safe and efficient motion planning: Manipulator arms are often used for tasks where the same movement is repeated over and over. In the case of bin-picking the randomness in the objects' pose means for every new object a new motion for the manipulator arm needs to be calculated on-the-fly. Some of the challenges we must consider is then how to ensure that robot can grasp the object without colliding with itself or the environment.

We have based our solution on algorithms developed in the SINTEF strategic project SEAMLESS. The idea was to use 3D sensing, extensive pre-processing of information about the robot configuration space, and dedicated hardware for parallelized computations, in order to calculate safe and efficient manipulator arm motions. Based on the sensed environment, the system could make the manipulator arm avoid colliding with people who are trying to obstruct it, and quickly re-plan a new way towards its goal. Within this project we have extended this functionality to also include contact operations. Were as previously everything could be considered an obstacle, the system will now have to deal with objects which the manipulator arm is actually meant to grasp. The planning algorithm is being tested on a physical setup of a UR5 six degrees of freedom manipulator arm, with a Zivid 3D camera and a vacuum gripper attached to the end-effector. The setup is challenging from a planning point of view, but it also gives flexibility compared to a setup with a static camera.

Figure 4. The physical setup consists of a UR5 robot with a Zivid 3D camera and vacuum gripper.

Towards "batch size one" assembly with robots

In several spin-off projects managed by industry partners in SFI Manufacturing (Koprod, DAMP, S-FACE), the participating companies are striving towards the vison of "batch size one" robotic assembly of their products. This vision involves many unsolved challenges in robotics, but a common basic challenge is the system architecture and tools needed to solve the problem of "batch size one" robotic assembly. Within SFI Manufacturing, we are collecting information on different approaches and needs in the industry projects, and developing new generic tools and methodologies to get one step closer to true "batch size one" robotic assembly.

Architecture for assembly based on the product's digital description
The research has been focused on understanding the needs and developing the tools and architecture for "batch size one" robotic assembly. A generic architecture has been suggested, which is based on the digital description of the product such as CAD models, where the CAD models are fed with extended data that can be used to generate the assembly process. Furthermore, the process is automatically generated from the extended CAD data and stored in different file structures that in sum will be able to feed the process with the necessary information. A process generator then collects the necessary data and publishes this to the different users. A user in this context can be a simulation model, the physical robot, or a mixed reality consisting of both the physical robot and virtual objects, visualised through an augmented reality application. The idea of using these three subscribers is to support the natural iterative process of developing a new and safe robotic assembly process, without performing the first run on the physical equipment. And as the process data origin is the same for all three subscribers, a correction performed in the physical world (for instance the measured position of a part) will be automatically be reflected also in the digital twin.

Bridging the gap between the digital and real world
The main challenge currently, within the research work, is the connection between the "perfect" well-defined digital twin and the unpredictable varying real world. First, capabilities to align and calibrate the physical system with the digital twin demands integrated coordinate measurement systems, and sensor-based robot control (vision, touch probe, force control, etc.). The system needs to handle any system setup as well, where skills can be added to extend its capabilities in a generic manner. Future prospects of the research can be alignment and integration with the PhD work on robotic assembly with CAD information performed by Mathias Arbo, "Automatic grasping using deep learning" from WP 2.1, and SEAMLESS. The SFI research is done in close cooperation with the Innovation projects (IPN) Koprod and DAMP, managed by Mjøs Metallvare and Rolls-Royce respectively.

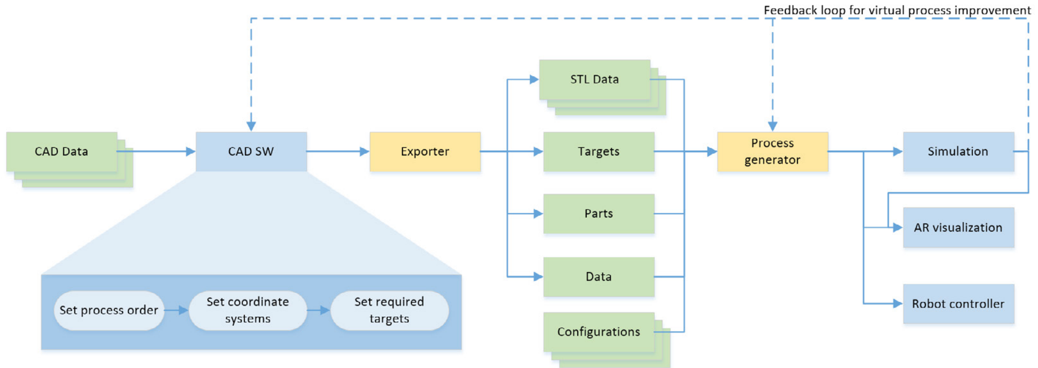


Figure 5. Framework for CAD-based programming method.

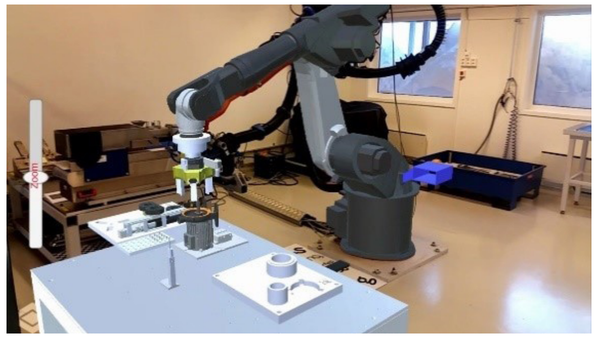


Figure 6. The physical robot hiding behind it's virtual twin in the AR-application.

PhD progress reports

Mathias Arbo – Robotic assembly with CAD information: Plan, skill and knowledge

Manufacturing automation is entering a new era, where a high degree of customization of the product is expected by the client to which manufacturers must adapt quickly. This era is associated with human-robot collaborative work cells, short time to deploy, and tighter coupling of design and manufacturing. To tackle this, we explore creating software systems that can plan the assembly sequence, choose skills based on CAD information and the robot environment, and handle arbitrary sensors and tight-clearance assembly tasks.

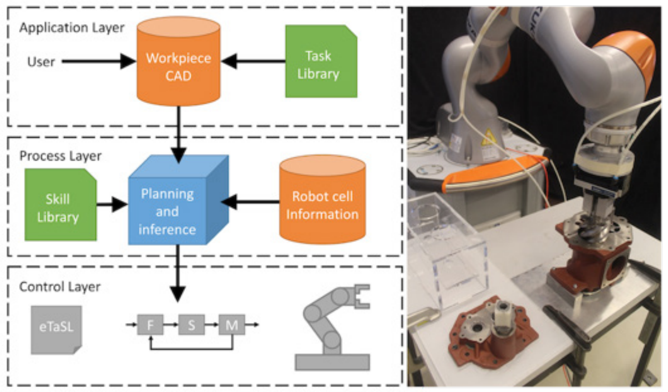


Figure 7. Prototype for a software system that can plan assembly sequences.

During a three month stay at Katholieke Universiteit Leuven, a prototype of such a system was developed by Mathias Arbo in collaboration with Yudha Pane, Wilm Decré and Erwin Aertbëlien. The prototype was presented in the article "A system architecture for constraint-based robotic assembly programming with CAD information" at the IEEE International Conference on Automation Science and Engineering (CASE) in August 2018, where it received the **best student paper award**. The article describes the overall system architecture, and focuses on how one defines skills, tasks, and how some parameters for the skills come from the CAD model, while others are empirical and must be generated using an inference module. Just as positioning parts in CAD is done by gradually constraining the part, constraint-based programming describes the motion of the robot as a set of constraints and finding a motion that fits with the constraints. What this means for manufacturing and some of the current research projects will be presented at the workshop.

One of the biggest hurdles with the prototype was in planning of both the assembly sequence and assembly motions. Generating the assembly sequence and planning the robot motions from an annotated CAD model would serve to bridge the gap between CAD and robotic assembly. This is a big topic with increasing interest internationally which deserves a Ph.D. tackling this using modern planning tools and artificial intelligence to exploit expert and CAD knowledge for real-life industry examples in SFI Manufacturing.

Linn Danielsen Evjemo – Metal AM by robot

AM technology has been quite limited when it comes to producing larger components, partly because traditional AM-processes build components "in-box": requiring the AM machine to be larger than the produced parts. One way of enabling additive manufacturing of larger components, is to combine AM with robotics, using a robot manipulator to extrude a fast-curing material, or combining it with welding equipment. Most of the flexibility for the shape and form of the final product in traditional AM-methods could be kept, or even improved. Overhangs (regions of material built over empty space, without support structures to hold it up) are one of the most basic limitations for traditional AM methods. This could be solved if we could utilize the full flexibility of a robot manipulator.

From glue to metal printing

Initial experiments were done using an UR-5 robot and an extruder of a type of viscous glue. This resulted in a paper that was presented at the Conference on Emerging Technologies in Factory Automation in 2017. The focus was then turned to AM in metal, combining an ABB robot with welding equipment, in collaboration with SINTEF Industry. We are mainly using Cold Metal Transfer (CMT) welding with aluminium but have also done experiments with arc welding with a nickel-based alloy. In future work, a complete, full-scale system for AM by robot manipulator needs to have some way of monitoring the process, and to give feedback on whether the build is going as planned or not, and ideally to compensate and correct weaknesses due to inaccuracies earlier in the build process. Three master students worked on problems related to this in the spring of 2018.

Results from the preliminary experiments doing metal AM by robot are not yet published, but the focus has been on mapping some of the challenges we face when trying to do large-scale AM in metal. So far, these experiments have been done on a horizontal surface with a fixed orientation for the welding gun. Experiments utilizing the full flexibility of the robot by changing the orientation of the head of the welding gun to build slightly more complex structures with overhangs are next on the agenda.

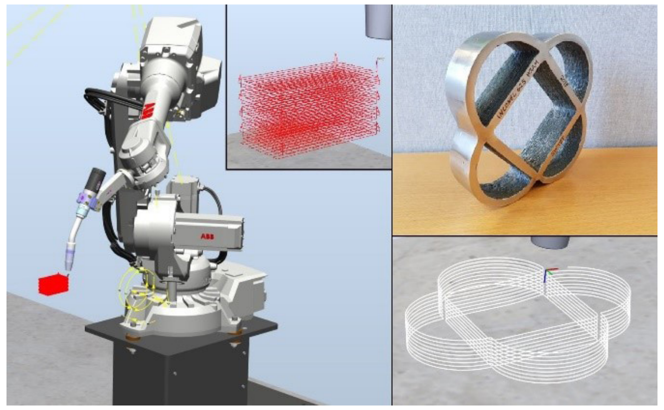


Figure 8. Combining an ABB robot with welding equipment.

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.

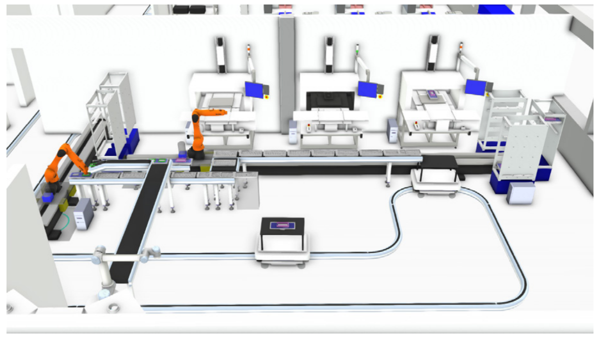
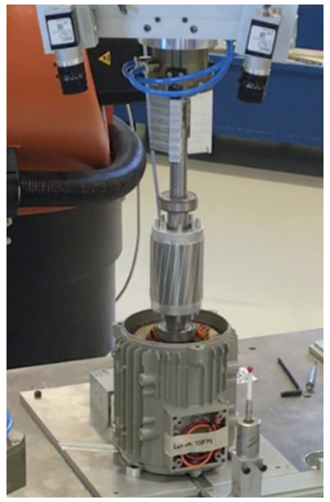


Figure 9. Simulation of the new moulding line.

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: Lars Tore Gellein, lars.tore.gellein@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 10. 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 at 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, 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 a focus area. 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 builts 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 SMB-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-sercive 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: 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 intesive 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 ques, 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.

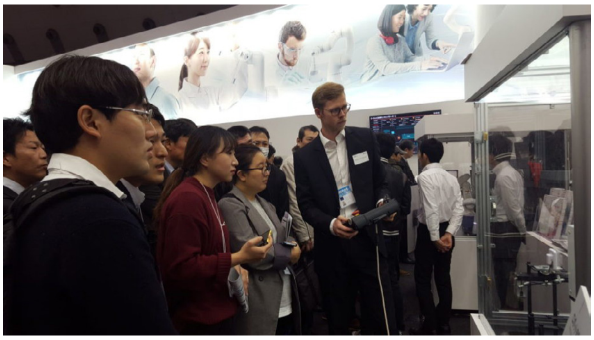


Figure 11. SINTEF's Øystein Hov Holhjem demonstrating the robot. Our collaborative robots, also known as "cobots", attracted a lot of interest.

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