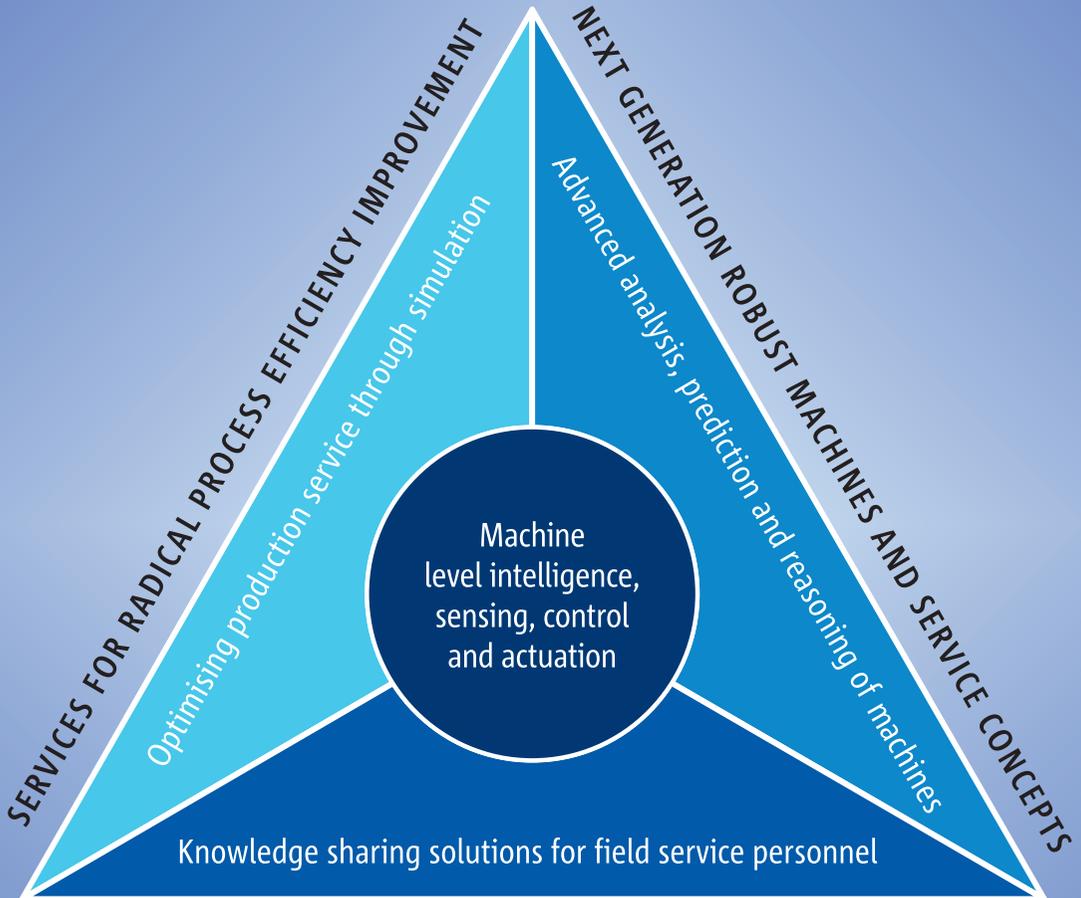


S-STEP – Smart Technologies for Lifecycle Performance



SERVICES TO EMPOWER HUMAN

DIMECC

FINAL REPORT 1/2017

S-STEP – Smart Technologies for Lifecycle Performance

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CONTENTS

PREFACE	
Kalle Kantola: Where leaders and winners meet	5
Arto Peltomaa: Step by step towards smart lifecycle management	6
INDUSTRIAL REVIEW	
Janne Kytökari: Growth and new business ahead!.....	9
RESEARCH INSTITUTES' REVIEW	
Petri Helo, Eija Kaasinen, Tommi Karhela, Tomi Krogerus, Matti Vilkkö: Industrial Internet technology for superior services	10
DIMECC S-STEP in a nutshell	13
1 MACHINE-LEVEL INTELLIGENCE, SENSING, CONTROL, AND ACTUATION	14
Project motivation and achievements	14
1.1 CASE WÄRTSILÄ: Combustion process measurements	16
1.2 CASE METSO MINERALS: Rock crushing	18
1.3 Energy autonomous pneumatic servo valve	22
1.4 CASE KONECRANES: The crane as process performance analyzer	23
1.5 CASE WAPICE: Embedded platform for condition monitoring data processing of rotating machine	26
1.6 CASE ABB MARINE: Testing and piloting of control systems and methods for Azipod®	29
1.7 Zero power sensor network	32
2 ADVANCED ANALYSIS, PREDICTION, AND REASONING	34
Project motivation and achievements	34
2.1 CASE WÄRTSILÄ: Optimal asset operation and performance of industrial engines	36
2.2 CASE KONECRANES: Reliability of lifting devices	40
2.3 Diagnostics	45
2.4 Reliability and prognostics	54
2.5 Collection, access, and interfaces to remote machinery data	59
3 OPTIMIZING PRODUCTION SERVICE THROUGH SIMULATION AND IMPROVED INFORMATION	62
3.1 Simulation-aided automation testing	64
3.2 CASE PRIMA POWER: Cloud-based O&M optimization	69
3.3 Predictive online simulation for the process industry	72
3.4 Cloud manufacturing	76

4 KNOWLEDGE-SHARING SOLUTIONS FOR FIELD SERVICE PERSONNEL	81
Project motivation and achievements	81
Mobile service technician	85
4.1 Preparing for maintenance	87
CASE WÄRTSILÄ: AR guidance, remote support, and preparing for a maintenance visit	92
4.2 Contextual guidance	95
CASE KONE: Mobile service technician	104
4.3 Remote assistance	108
CASE KONECRANES: The use of a haptic controller in remote operation	112
4.4 Data gathering and reporting	116
CASE BRONTO SKYLIFT: Mobile service technician	122
4.5 Contextual social media	126
CASE KONECRANES: Mobile service technician	130
4.6 Providing situationally relevant information	135
CASE 3D Studio Blomberg: Case Vamp AR	140

Where leaders and winners meet

Novel service business is the key driver for new business creation in various industries. In particular, digitally enabled services will play a key role in companies' future growth, and emerging modern technology solutions, like the industrial Internet and advance analytics, will enable even the most challenging vision to become reality in near future.

DIMECC's S-STEP program was designed to drive the initiation of industrial services from the technology side. Its mission to enable an S-curve step, meaning to raise devices' embedded intelligence to the next S-curve, is critical. This is because, without effective device-level operations or robust and reliable information from devices, modern fleet-level service business would not be profitable nor sufficiently responsive to change based on dynamic conditions. To enable these, all manual and low-performing operations needs to be automated.

The same requirement applies to the innovation ecosystem, and especially to co-creation, in which various highly skilled experts are working toward common goals. These kinds of activities require effective platforms and cooperation models that ensure effective cooperation among individuals and maximum utilization of all expertise toward the common goal. DIMECC focuses on this issue, and our mission is to create the leading co-creation platform for digital innovation and transformation. Through this, we enable effective co-creation by top experts and aim to raise the speed of innovation to the next level.

Examples of effective co-creation can be seen in this final publication. I would like to warmly thank our S-STEP consortium for their great work and cooperation. In particular, I would like to acknowledge the efforts of Dr. Jouni Pyötsiä and Dr. Olli Ventä in their visionary and critical work in program preparation, Dr. Arto Peltomaa for his effort as program manager and thus as the key architect in enabling effective cooperation.

Although this is the final publication, the journey toward the next S-curve under the DIMECC ecosystem is just beginning. Empowered by the shareholders from leading engineering and ICT industry players, DIMECC itself has also reached the next level in the innovation ecosystem. We are the platform where winners and leaders meet. You are welcome to join us!



Dr. **Kalle Kantola**
EVP, Strategy
DIMECC Ltd

Step by step towards smart lifecycle management

The DIMECC S-STEP program was positioned in the crossroads of two megatrends: the growing importance of industrial service business and the emergence of the industrial Internet. The combination of these trends was considered to offer significant advantages for Finnish industries and exports.

The vision of S-STEP was that profitable industrial services require reliable knowledge. This means that, to produce competitive new product-related services, companies need deep knowledge on the product throughout its whole product life-cycle. The knowledge is gathered during the design, operation, and recycling phases with help of the industrial Internet.

The past two years, since start of the S-STEP program, have proven that the industrial Internet is transforming manufacturing, products, and competition in practically all industries even deeper and faster than expected in the preparation phase of the program. The evolution of products into intelligent, connected devices is radically reshaping companies and competition. The past two years have also strengthened the view that growing the service business is vital to maintaining a competitive heavy metal industry in Finland. The program preparation team, consisting of DIMECC, industry, and academic representatives, deserves warm congratulations on the most successful focus of the research work. The whole S-STEP consortium has enjoyed working and contributing in areas that are top priorities in the updated strategies of companies and research institutes.

Realizing industrial Internet opportunities in complex investment products like power plants, industrial lifting devices, and metal manufacturing machinery requires increasing cooperation among machine manufacturers, the ICT sector, and research institutes. In the S-STEP program, an ecosystem consisting of major Finnish machine manufacturers and leading research institutes has been created to solve key research challenges. This ecosystem and the achieved research results can serve as an effective stepping-stone toward the next wave in digitalization and industrial Internet progress in Finnish industry.

This publication aims to report the key results of the S-STEP program, mainly from the industry impact viewpoint. Especially taking into account the short duration of the program, only two and a half years, the results are most impressive.

The S-STEP program consisted of four work areas that approach industrial Internet research challenges from different angles.



Each of the four work areas has results that already increase the product and service sales of the participating companies during the next few years. One key factor behind the S-STEP success has been the exceptional commitment of the globally acting machine manufacturers like ABB Marine, Bronto Skylift, Kone, Konecranes, Metso, PrimaPower, and Wärtsilä. These companies have demonstrated their willingness and capability to carry out open, networked, and agile research with universities, research institutes, and SMEs. This has created a most motivating and inspiring atmosphere for the whole consortium.

Committed industry partners, experienced and talented research resources, and a fruitful work area form a winning combination. In the S-STEP program, those three prerequisites have been fulfilled in a beautiful way. All the research partners have responded to the industry challenges with enthusiasm and hard work. I want to thank the whole S-STEP research community for their most valuable contributions. I would like to give special thanks to project managers Prof. Petri Helo, Dr. Eija Kaasinen, Prof. Tommi Karhela, Dr. Tomi Krogerus, and Prof. Matti Vilkkö. Their expertise and professionalism has formed a steady backbone for the program execution.

The industrial Internet and growing the service business will still be important research areas in Finland many years from now. I am very proud of the S-STEP achievements, and hope that all the results, including this report, will be widely and actively used to generate the next high-impact steps.



Dr. Arto Peltomaa

Program Manager, S-STEP
DIMECC Ltd

Growth and new business ahead!

Digitalization and utilization of smart technologies are the topic of the day. There is real eagerness to adapt new digital service and operation models to boost traditional business. Consulting companies and global information technology giants vow that digitalization will be the next giant leap in the timeline of industrialization. Digitalization has been discussed for far longer, however, especially among academics, and in truth it has already started to mold our lives since the invention of computer. Now, however, the technology has become and is becoming cheaper and cheaper, with microscopic chips able to transform data into real information and transfer it to the right end-users, whether they are other machines or people.

The digital transformation does not come without growing pains. While it is easier to calculate and move data, the physical phenomena and measurement of it are vital to its success. Cheap sensors are useless if they do not measure the right variables, if they do not provide reliable data, or if they cannot survive the harsh environment in which they are placed. Replacing field sensors with soft sensors and understanding the process and the causal patterns become more and more important over time. All these questions were, and continue to be, a key area of research for Metso Minerals.

Overall, the DIMECC S-STEP program speeded up the research and study of how simple measurements, on-site computing, transfer of data, and cloud analytics can actually bring benefits to end-users, no matter

whether they adapt technology fast to gain advantage in their own market, or rely on proven technology unless real practical benefits can be shown.

New technology may also present original equipment manufacturers with difficult strategic situations in which utilization may rise to become a threat to the present business. At the same time, new business opportunities arise. Digital services such as data-as-a-service models, remote support, and life-cycle services provide a field in which the current OEM business can grow, while increasing customer satisfaction and, in the end, customer profits. These need to be at the heart of any digitalization roadmap, and I believe that this was the initial thought in the S-STEP program, as well.



Janne Kytökari
Global Director
Monitoring and Control
Technology
Metso Minerals

Industrial Internet technology for superior services

The DIMECC S-STEP program consists of four research areas with the common goal of creating the industrial Internet technology that enables superior services for Finnish industry, each tackling the research question from a different angle.

The background of the research area ***Machine-level intelligence, sensing, control, and actuation (MASCA)*** was that service businesses lack operation and condition information from processes and machines that operate in harsh conditions. Traditional instrumentation is primarily designed for technical control purposes, not to collect information for later use.

The main observations have been that the harsh conditions cause unexpected restrictions to data collection arrangements; the measurement range and bandwidth limits of the low-cost sensors have to be taken into account; and they limit the applicability in some solutions. Data transfer in remote monitoring applications worked better than expected, with an up-time of several months.

One new kind of function was observed to be of importance in remote monitoring applications. Since the local sensor network does not transfer all raw data to monitoring agents, some sort of processing application has to operate locally. This application contains filtering, outlier detection, data reconciliation, and validation. This application should be developed and maintained remotely.

The motivation and the driving force behind research area ***Advanced analysis, prediction and reasoning*** was the fast development of condition-based maintenance systems of industrial systems. The goal of the research was to study and develop new data analytics methods and their applicability to diagnostics, reliability analysis, and prognostics in different application areas. During DIMECC S-STEP program, the following were tested: marine engines (black-box, active load limitation, common rail diagnostics, operational profiles, gensets) and lifting devices (usage profiles, reliability modeling).

The following important observations were made during the program. Sensor and data quality is an important issue, and extra attention should be paid to it already in the design phase. This is needed to be able to build reliable, sophisticated service solutions based on advanced data analytics, because these are totally dependent on reliable, accurate (real-time) data. Efficient and sophisticated algorithms and methodologies have already been developed in other science areas and should be ex-

exploited more in the analytics of machinery. New methods of cleverly combining various multivariate disparate data are needed to fully exploit the potential that is hidden behind all this big data.

In research area ***Optimising production service through simulation and improved information management*** the focus was on modeling and simulation (M&S). M&S is an efficient and widely used method of systems design. However, M&S is seldom used for systems operation, mainly because tools are scarce and restricted to specific applications.

Firstly, we developed a tracking simulator-based predictive online simulation system (POSS) for the process industry. A tracking simulator is a simulation model that is run in parallel with a physical process controlled by the process control system. The development was carried out using a laboratory process and a parallel dynamic process simulation model. The main observations have been that the POSS system can be an excellent tool for prognosis, fault diagnostics, and soft sensing.

Secondly, we utilized M&S in the interface between design and operation. Simulation-aided testing of a control system is a powerful tool for ensuring the quality of automation delivery. We developed methods and tools for automatic model generation from design data, and a toolset for systematic control system testing. We tested the methods and tools against a minerals processing control system delivery project, together with the participating company.

Thirdly, we defined an integration architecture for integrating M&S into systems operation. The architecture is based on OPC UA, and as a part of the architecture we have also defined a standardized path for design system information during operation time. This has been done by expressing a plant design specification called Proteus/Dexpi using the OPC UA data model. The resulting specification has raised interest in international consortiums like the OPC Foundation and the Dexpi group. After the S-STEP program, a common effort will be started to generate an official international OPC UA companion specification based on this work.

In the research case ***Sheet-metal manufacturing***, the uses of mathematical optimization has shown promising potential. We analyzed the potential of various processes: the selection of machinery in the investment phase, the design to production phase, the production planning phase, and finally the production execution phase. The optimization approach presents possibilities in all areas for the improvement of efficiency and resource utilization. By using sequencing and scheduling for the production plans, capacity utilization can be improved by several per cent.

During DIMECC S-STEP program, we developed a genetic algorithm-based scheduler that can be tailored for each production line and company. The solver minimizes the given objective function efficiently and can quickly propose alternative production plans. From an architecture

point of view, the use of cloud computing for centralized production planning services and automated optimization seems to be a powerful solution. Several machines or production lines can be online with the server by using Internet connections from smart devices.

The research area **Knowledge sharing solutions for field service personnel** was focused on the opportunities and challenges that the industrial Internet and service business will introduce to industrial work. We focused on knowledge-sharing in field maintenance work, as the participating companies have a strong and growing focus on maintenance services.

Together with the companies, we developed knowledge-sharing solutions that support preparation for a maintenance visit, troubleshooting, the actual maintenance operation, and finally reporting. Omnidirectional video equipped with hotspots with detailed guidance turned out to be a promising solution for sharing knowledge on maintenance sites and targets before a maintenance visit. Augmented reality turned out to be an efficient way to give contextually relevant hands-on support in a contextually relevant form in different maintenance tasks. Augmented reality can also efficiently support collaboration with remote experts. Omnidirectional video and speech interaction were promising tools to ease and automate reporting. This was one of the most important features that field service professionals were looking forward to, as reporting needs are continuously growing. Peer support through contextual social media is a promising concept that was well accepted in user evaluations.

We wish the readers inspirational moments with the S-STEP report and DIMECC outcomes.



Petri Helo
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DIMECC Smart Technologies for Lifecycle Performance (S-STEP) in a nutshell

Company partners:

3D Studio Blomberg, ABB, Bronto Skylift, Control Express Finland, Comatec, Fortum, Ixonos, John Deere Forestry, KONE, Konecranes, Mantsinen, Metso Flow Control, Metso Minerals, Mevea, Outotec, PrimaPower, Wapice, Wärtsilä.

Research institute partners:

Aalto University, Lapland University of Applied Sciences, Lappeenranta University of Technology, Novia University of Applied Sciences, Tampere University of Technology, University of Tampere, University of Vaasa, VTT Technical Research Centre of Finland Ltd, Åbo Akademi University.

Program:

Duration:	1.6.2014 – 31.12.2016
Budget:	11.4 M€
Company budget:	6.2 M€
Research institute budget:	5.2 M€
People involved:	120

Results:

Estimated business increase 2020:	450 M€
DIMECC Prize wins:	1
Number of publications:	35
Number of academic theses:	10
Research exchange months:	9

Project motivation and achievements

Novel IoT solutions are typically developed for processes and systems that have no traditional automation instrumentation. It is typical for these applications that the parts of the process components are mobile, are difficult to instrument, and have separate or otherwise challenging power supplies. These conditions imply challenges such as grounding problems, special requirements for data acquisition A/D converters, shielding of channels, protection of over voltages, and so on.

In MASCA, several important parts of the overall industrial internet architecture have been developed. The project had elements of wireless communication, sensor development for harsh conditions, sensors for operating environment observation, remote monitoring and operation, even remote commissioning, instant sensor attachment for moving machines, and sensor systems for testing purposes, to name a few.

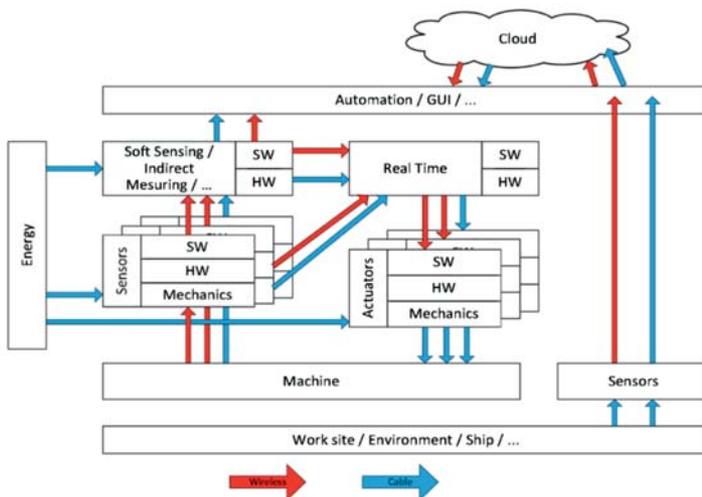


Figure 1. Architecture for IoT systems

IoT applications are sometimes planned to be implemented using legacy PLCs and DCSs. Sometimes their usage sets additional and unexpected constraints on applications. Typically, unexpected situations arise when there is a need to access the field buses of these legacy systems. DCSs and PLCs are supplied by several companies, and the field bus implementations can contain undocumented and non-standard features. Usually there are no documents and no access to these features. Another issue is the application software that has been developed to control the processes.

Similarly, some of the features has been developed since the commission, and sometimes they are not documented. Some of the new features have been developed since the process has changed and some, because some of the components, had to be changed due to a malfunction or break-down.

These are the issues for which an IoT application developer has to be prepared. The issues can be solved using ordinary automation engineering expertise. Therefore, it is essential in the application development that expertise in automation engineering and domain knowledge is connected to expertise in IoT technologies.

In the following chapters, the applications developed in MASCA are introduced. In the Wärtsilä case, the means to measure the combustion chock pulses were developed. In the Metso case, off-the-shelf IoT sensors have been modified so that they can be installed and used in a harsh rock-crushing environment. Konecranes used image sensors to detect the working environment, and combined the data with data from other sensors. Wapice developed, together with other parties, a computational environment that can be integrated with their IoT platform. ABB used sensors to detect operation ranges that induce unwanted vibrations, and used the data to define the most favorable operation conditions.

These results of the MASCA project show that with the IoT paradigm, it is possible to develop novel applications that give better understanding of the operation of the machinery, and the conditions of operation. Using this information, it is possible to develop services to improve performance, monitor conditions, and evaluate maintenance needs.

CASE WÄRTSILÄ: Combustion process measurements

Background and objective

With increased demands to decrease the environmental impact and increase the efficiency of marine and power plant combustion engines, the monitoring and control of the combustion process itself is becoming more important than ever. In order to cope with these demands, Wärtsilä is developing technologies that, as a result, make firing pressure levels become higher. At the same time as this requires better control of the combustion process, it also makes monitoring of the environment very challenging.

In the S-STEP project, the overall objective was to develop state sensing systems tolerant of an extremely harsh combustion process environment. This calls for robust and accurate sensing equipment that is durable enough to withstand extremely harsh environments. Indirect instrumentation and measurements, methods, and data models can also be utilized. One of the additional objectives was to develop methods of testing the key equipment to validate its performance before operational use in engines.

Results

Several laboratory engine tests were conducted in order to learn the causes for sensor failure, as well as to identify the weak points in the structures. A survey was carried out to evaluate options for combustion process measurements and sensor options to withstand the extreme combustion events present during demanding running conditions. Based on the survey, planning of pressure sensor test rig concepts for the generation of shock pulses, with adjustable pressure pulse properties to mimic engine firing cycles, was executed. The properties of the most valid concepts were tested using model-based simulations, and the most promising, rifle-based solution design was finalized at the concept level.



Impact

One outcome was increased awareness of different circumstances and factors affecting the cylinder pressure sensor lifetime and how to test it to ensure its long-term operability in a harsh environment. The new knowledge will be used as a base when developing new sensor failure diagnostics functions, and when improving sensor designs. In a combustion engine environment, better and more durable monitoring capabilities is one of the most important cornerstones in increasing the efficiency level and reducing the environmental impact.

CASE METSO MINERALS: Rock crushing

Background and objective

Aggregates are granular material that is used in a wide range of constructions, like railroads, infrastructure, and buildings. Aggregates such as sand, gravel, or crushed rock are extracted from quarries and pits. Aggregates can also be produced from recycled material from demolished constructions. In the aggregate and mining industries, the product needs to meet application-specific requirements. The most common demands are a cubical shape and a certain particle size distribution. These can be satisfied by proper selection and the use of crushing and screening devices.

One unfortunate feature of crushing plants is that methods for determining the size distribution and shape of produced rocks are not typically carried out in real time. The most common way is to take a daily sample and send it for laboratory analysis. There are devices for measuring size distributions based on optical measurements, but these have not been widely adopted in crushing plants due to the difficult outdoor conditions, which necessitate the use of protective covers that then increase the price of such installations.

Crushing plants are divided into two main categories: mobile and stationary. Both types of plant consist of the same main devices, such as crushers, screens, and different kinds of feeders and conveyors, which are connected in series or parallel to each other. The main difference is that stationary installed plants require more loading and hauling than mobile plants, because they cannot be moved along the quarry face, but mobile plants are usually mounted on tracks and can move as the blasting of the rock progresses. Stationary plants typically have higher capacities than mobile ones.

The selection of the plant setup depends on the required products and capacity. Feed material characteristics, such as feed fraction, moisture content, material density, crushability, and abrasiveness, have an influence on the selected setup of process devices, too. Mobile track-

mounted units require caution from the user, because process devices such as crushers and screens are designed to be placed horizontally on a solid surface.

In Europe, 15 000 companies produced 2.6 billion tonnes of aggregates in 2013, which means revenue of around 15 billion euros. Those companies employ more than 200 000 people, and the production of aggregates occurs in 25 000 quarries and pits. The production tonnage and the turnover give a rough estimate of the average income per produced tonne, which is €5.80/tonne. In conclusion, it can be said that the profit in the aggregate industry comes from high volume production. For instance, the maximum capacity of a Metso Lokotrack LT300GPB mobile crushing plant is 450 tonnes per hour, so in the worst-case scenario, every lost eight-hour production period means almost €21 000 of lost income.

Results From a customer point of view, high volume-based production requires that process downtime is minimized, especially on sites where strict environmental requirements set time limitations concerning when crushing is performed. Unexpected device failures lead to extra delays before the process is up again, because damaged parts may be more difficult to change, or the feed material may have to be removed manually before repair. When failures are anticipated, several maintenance actions can be executed at the same time without extra process stops. The second point of view for condition monitoring is to avoid running the process in a disadvantageous way. These kinds of situations may be, for example, resonance in conveyors, excessive wear in crusher parts, and high vibrations in the crusher motor. The safety aspect cannot be ignored, either.



Figure 1. Sensors installed on the main conveyor

Total device breakdowns cause exceptional situations and, as a consequence, are favorable conditions for accidents. These situations can include dangerous lifting or the use of power tools that would not be needed if maintenance had taken place before device breakdown.



Figure 2. Sensors installed in the Lokotrack frame

Even in minor issues, the costs are usually thousands of euros, since in addition to the spare parts, the costs consist of maintenance personnel travel expenses and the time spent identifying and repairing the fault. With predictive monitoring, in addition to the actual fault, other evolving faults can be repaired during one service visit. This reduces unexpected process stops and downtime, which is good for the reputation of Metso. Other benefits for Metso are that system monitoring may give more details about failure root causes and possible improper use of the devices. These kinds of misuse situations include, for example, Lokotrack being placed on an inclined surface, or the crusher being used with too small a setting. In these situations, the resultant forces in the crusher can exceed designed values.

The results include promising application-specific condition-monitoring methods and a promising concept for collecting, processing, and storing process data, and remotely monitoring rock-crushing processes. The condition-monitoring methods are demonstrated in one mobile plant in Finland. In turn, the process data-related concept is demonstrated in two crushing sites in Finland and Sweden, of which one is stationary and the other is a mobile plant.

The condition-monitoring tests are implemented with both wireless and wired sensors. The wireless sensors represent lower price segment devices, but the wired sensors are actual industrial sensors.

Impact The research done in S-STEP opens opportunities to improve the monitoring capabilities of crushing equipment. There are still challenges to solve, especially when using wireless sensors in this environment, such as battery life, synchronization of measurements, and combining high sampling rates with limited bandwidth and device processing capacities. These challenges are exacerbated by the requirement to make these devices fit into the low-cost category instead of being expensive specialized measurement devices.

Nevertheless, there are significant findings in how vibration and orientation measurements can help with condition monitoring. The fact that connectivity is, nowadays, a standard feature in machines makes it feasible, and even necessary, to equip machines with sensors that are not strictly required for safety or machine protection. This is a significant cultural change in machine production, where sensors have largely been a “necessary evil” instead of an enabling technology for life-cycle business.

Lessons learned Novel IoT solutions are typically developed for processes and systems that have no traditional automation instrumentation, but there are also solutions that are planned to be implemented using legacy PLCs and DC-Ss. This can set unexpected constraints on applications, especially when connecting to the field bus. Different suppliers use different field bus types and standards. A more challenging issue is that field bus communication can contain undocumented and non-standard features, and some of the traffic can be so application-specific that suppliers would like to keep the data secret.

Wireless sensors require sensor-level intelligence, because sometimes the required measurement frequency is higher than the wireless network can handle. In addition, multi-sensor trajectory measurement needs to be time synchronous, so that anomalies can be detected. Moreover, the heavy steel structures of a crushing plant are a challenge for radio reception, due to the loss of line of sight and unpredictable reflections.



Company impact

“Overall, the DIMECC S-STEP program speeded up the research and study of how simple measurements, on-site computing, transfer of data, and cloud analytics can actually bring benefits to end-users.”

Janne Kytökari, Global director, Monitoring and Control Technology/Metso Minerals

Energy autonomous pneumatic servo valve

Background and objective

Traditional pneumatic servo valves have continuous leakage and thus big losses. Servo valves are also sensitive to air impurities. In the area of hydraulics, the sensitive servo valve has been successfully replaced in some applications by a set of simple and reliable on/off valves – so-called digital hydraulics. The objective of this project was to study whether the same is possible in pneumatics, too. The expected benefits were zero leakage, insensitivity to impurities, and improved performance via faster valves. A special challenge was that the energy usage of the solution must be extremely low. The objective was that the solution can use just energy taken from the fieldbus, without any additional power supply.

Results

The main result is that a digital pneumatic approach results in good control performance and can, in this sense, be used to replace servo valves. The second result is that only a few valves are needed in order to achieve good performance. However, the requirement of ultra-low power usage was not satisfied, but needs further research. The conclusion is that the technology works and is interesting, but it is very difficult to satisfy the low power requirement.

Impact

There is no immediate impact on product development. This is due to the relatively high cost and electrical power demand of multiple pneumatic valves. Further research should continue on the low-cost implementation of individual valves, on minimizing the number of valves, and on minimizing electric power consumption.

Heikki Mesiä/Konecranes

Julia Malysheva, Tuomas Eerola, Heikki Kälviäinen, Lasse Lensu
Lappeenranta University of Technology

CASE KONECRANES:

The crane as process performance analyzer

Background and objective

The intelligent machines of today are aware of their use and state, but they should also become more aware of their close environment. This challenge can be solved by adopting physical and virtual sensor systems that fit the purpose.

Intelligent 'soft' sensing enables the gathering of information that is difficult to measure directly. The applicable solutions include the use of multisensory and model-based indirect measurement methods that combine readily available machine data with measurements, thus creating soft sensor combinations. By communicating with each other, the sensor systems can produce value-adding information for other machines, applications, and operators.

Process cranes are operated high above the production lines. They have a splendid bird's eye view over their working area, but this advantage is not fully exploited. The S-STEP research has targeted adding to the crane the senses it needs. With its enhanced capabilities, the crane, in addition to its primary functions, becomes a source of reliable dynamic information for the factory, supporting the efficiency and safety of the processes.

Results

Case 1 focused on the 3D detection and mapping of the changing environment and layout in indoor halls and storage areas in near real time. The relevant results include the build-up of a field-applicable sensor rack containing an RGB camera, LIDAR scanner, and thermal camera. The sensor rack was used to collect field data in an industrial factory hall. The data was further processed to develop methods to construct point clouds from the LIDAR data, and to fuse them with the RGB and thermal camera images (see Figure 1). The results enable the support of production and material handling processes in tracking items in the factories and in visualizing the factory layout and crane operations.

Case 2 focused on utilizing the results of Case 1 for monitoring waste material properties as part of the waste incineration process. In this context, appropriate information on the waste material supports the optimization and efficiency of the burning process. The crane is the only machine in close and direct contact with the material. The harsh conditions make it difficult to use direct methods to estimate the waste properties. The relevant results include a field test, with the developed sensor rack to collect a set of field data in a waste bunker (see Figure 2). The resulting aligned multimodal data can be used to extract and segment 3D objects in the environment, and further to construct methods that enable cranes to recognize unwanted objects in the bunker.

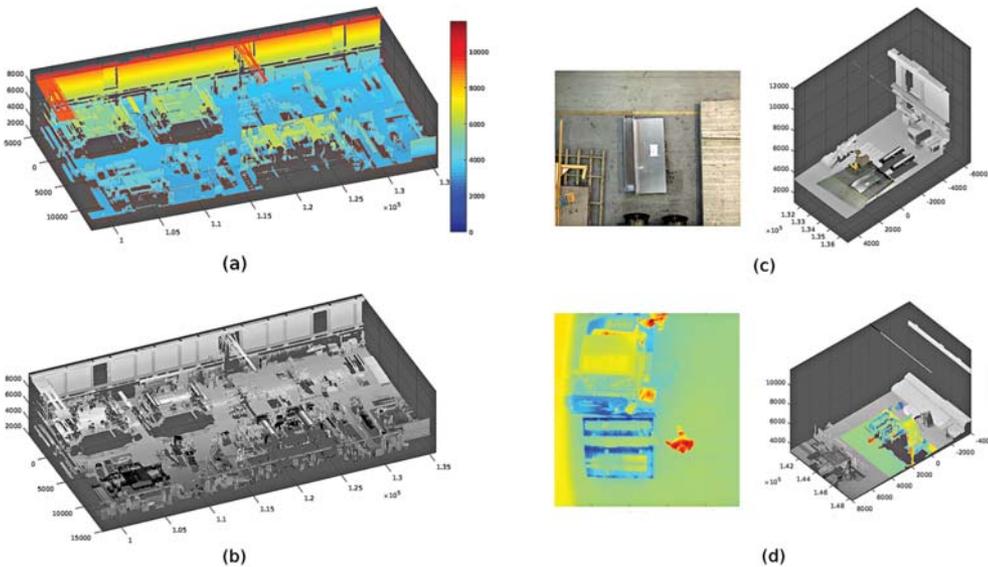


Figure 1. Multimodal data from an assembly line: (a) A point cloud with the elevation visualized using different colors; (b) A point cloud combined with LIDAR intensity values corresponding to reflectivity; (c) Aligned and fused LIDAR and RGB data; (d) Aligned and fused LIDAR and thermal data

Impact The obtained results create novel possibilities to develop cranes that sense their surroundings. For example, the operational safety on a production line can be greatly improved, the performance of an assembly line can be monitored, and the efficiency of the waste incineration process can be enhanced through improved storage handling, supporting better homogeneity of the material and the detection of harmful and unwanted objects. The results support a new vision of thinking beyond the current technology and seeing the individual pieces of equipment on the production line as components of a larger system, so that they support and communicate with each other, and work together. This is one

step toward realizing the IoT in an industrial context. Money, time, and percentage-wise benefits and savings are not easy to estimate, as they are application dependent, but in continuous large-scale processes, the benefits are substantial.

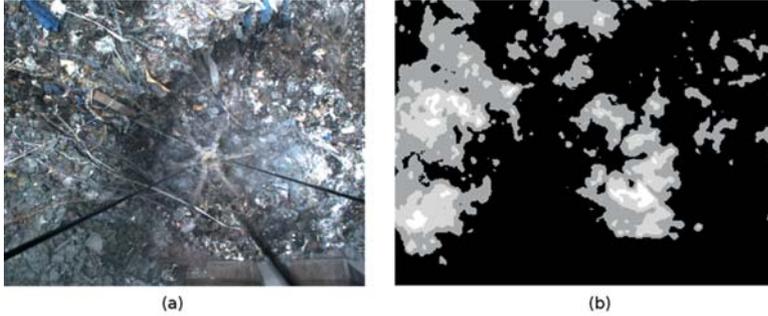


Figure 2. Image data obtained from a storage bunker at a waste incineration plant: (a) RGB image; (b) Corresponding heat map obtained using the thermal camera

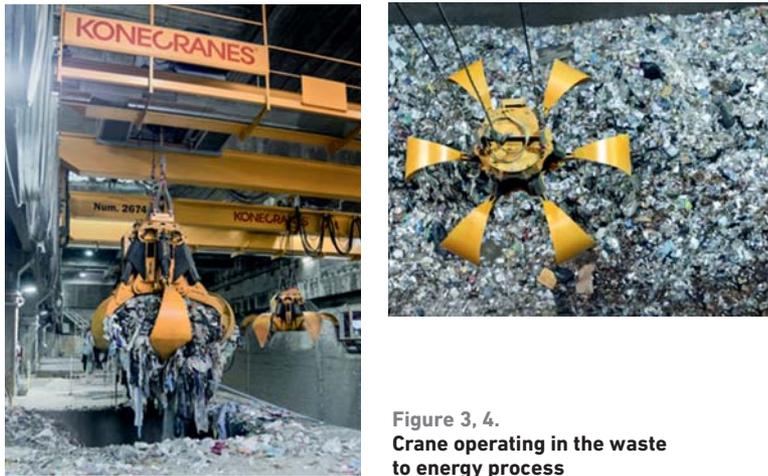


Figure 3, 4. Crane operating in the waste to energy process



**Company
impact**

"The S-STEP results support a new vision of thinking beyond the current technology and seeing the individual pieces of equipment on the production line as components of a larger system, so that they support and communicate with each other, and work together."

Heikki Mesä, Senior Specialist/Konecranes

MACHINE-LEVEL INTELLIGENCE, SENSING, CONTROL, AND ACTUATION

Veli-Pekka Salo/Wapice
Jussi Aaltonen/Tampere University of Technology

CASE WAPICE: Embedded platform for condition monitoring data processing of rotating machine

Background and objective

The number of devices connected to the internet has been growing exponentially for the last few years. The demand to analyze huge amounts of product or business domain-related data, gathered by IoT-enabled applications and devices, has created a requirement to establish new analysis and decision-making functions to optimize product-related development processes.

IoT-Ticket (www.IoT-Ticket.com) enables operational efficiency and business model innovation for industrial companies. The platform supports supervisory monitoring, control, automation, and advanced reporting functions. By adapting industrial standards, the platform enables efficient condition, maintenance, and reliability management.



Figure 1. IoT-Ticket architecture

The Simulink IoT interface investigated in the S-STEP project is one solution to bring analysis, modeling, and decision-making functions closer to the data. It enables developers and researchers to be part of the growing trend of getting connected to devices over the internet.

MATLAB is a widely used environment for mathematical calculations, and Simulink is an object-oriented development tool built over MATLAB. With the Simulink IoT interface, people using Simulink can now easily connect to IoT, collect and write data from IoT, and, of course, run simulations or examine data from IoT.

Results In the S-STEP project, the Engineering Intelligence Laboratory from the Tampere University of Technology utilized the IoT Ticket platform and Simulink interface to model an industrial water hydraulics process.

The water hydraulics process pilot environment was constructed at the TUT Engineering Intelligence Laboratory. It consists of a pump, a directional valve controlling the flow to a motor actuating a rotor, and a water level indicator. The control current of the valve, pressure in the main line, rotational speed of the motor, and water level were monitored. The collected data consisting of these four sensor measurements provided an overall view of the operation of the system. Wapice provided a WRM247+ device that was used for data acquisition, while the data processing and visualization were executed using the IoT Ticket platform.

A Simulink model of the water hydraulics system was created by utilizing information about the system and its components, and was verified using the sensor data collected from the system. Using the IoT Ticket-Simulink interface, both measurement values and simulated values could be examined and visualized in IoT Ticket.

A conceptual model-based fault-detection system was then explored using these two datasets. The concept was to optimize the parameters of Simulink in order to fit them to the measurement data. The parameter changes made during optimization were recorded and then examined in order to estimate which components or parts of the system were the source of differences in the comparison between the measured and simulated values. The optimization and parameter fitting were done using the Techila cloud-based computing solution, which enables efficient operations on very large datasets.

The whole process, which consisted of preparation of the data acquisition system, creation of the Simulink model, and utilization of the collected data to verify the model, was used to test the implementation of the system for model-based decision-making in an industrial environment. It provided information on how to implement ready-made IoT platforms and data acquisition tools for industrial processes, and how to utilize them with a self-made simulation model.

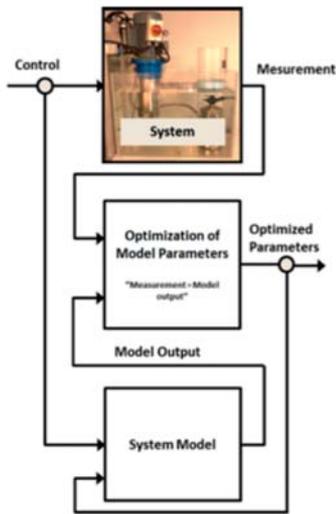
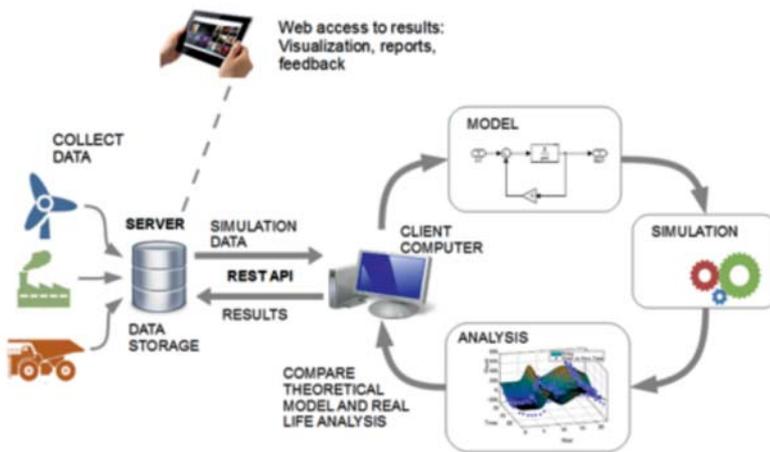


Figure 2. The water hydraulics process pilot environment



During this project, Wapice investigated the requirements for analytics, modeling, and decision functions in an IoT platform, got feedback from platform users, gathered lessons learned from system simulation in an industrial environment, and demonstrated platform interfaces and big-data analytics capabilities.

Impact The Simulink IoT interface is a new innovative way to connect analysis and decision-making functions using IoT data sources. It enables rapid prototyping of simulation models, data analysis methods, and model-based design in the context of industrial IoT. The Simulink IoT interface introduces a new way of connecting product development with IoT-enabled industrial applications, and thus reduces product development costs, speeds up the time to market, and optimizes system or software development practices.

CASE ABB MARINE: Testing and piloting of control systems and methods for Azipod®

Background and objective

Azipod® is a typical externally loaded structure whose main loads and load cycles are caused by hydrodynamic interaction and are generally not as well-known as, for example, in the crane industry, while at the same time the effect of its own weight in dimensioning is small. For these reasons, more exact understanding of various hydrodynamic and vibration phenomena is important and will help to focus changes just on where they are needed, and to reduce material costs where possible.

Results

The following results have been developed:

The load measurement system is developed to a level of standard assembly, which can be readily installed on any Azipod® propulsor. The system delivers reliable data, which can be synchronized with various ship operating parameters. The system provides understanding of load levels at various operation points, and can be utilized to provide the operator with operation recommendations in order to maximize lifetime and reduce maintenance and service costs. Further, the system can be utilized to verify and calibrate hydrodynamic load definition methods. Extensive operational vibration data has also been collected in cooperation with VTT. Various critical components, including the Azipod® hull, have been measured.

Based on the data, it is possible to implement either a data-based operator guidance system, which bars those combinations of operational parameters that possibly lead to unwanted phenomena, or a measurement-based guidance system, which alerts the user based on direct load and vibration measurements.

Based on vibration measurements, both passive and active vibration damper concepts have been studied and tested. The passive method is based on an application of the "REKI" wide spectra damper, which was

originally developed by VTT. It has been tested to good effect in locally reducing vibration levels of components of the Azipod® assembly. The active method is a new method for podded propulsors. It is based on the idea of adjusting the electric motor torque so that motor inertia is actively used for a damping effect.

The idea of measurement-driven operating guidelines is illustrated in Figure 1.

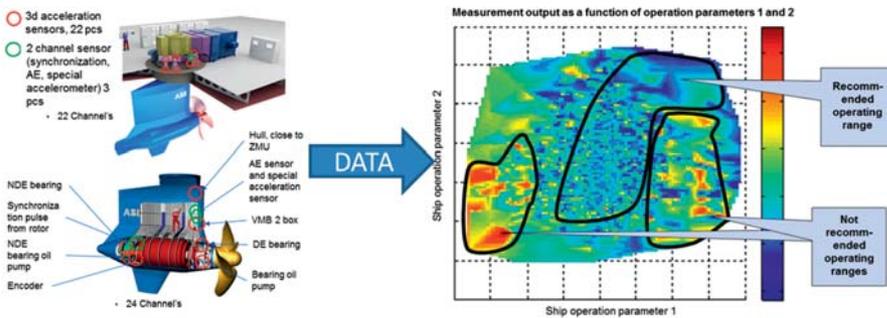


Figure 1. Measurement-driven operating guidelines

Impact of measurements and measuring system

The initial cost can be reduced by implementing the S-STEP project results in Azipod® design principles. The measurement data and measurement system are essential in calibrating the hydrodynamic and operational design assumptions to match real operation. They are a valuable asset in differentiating from the competition.

The lifecycle cost can be reduced by utilizing the S-STEP data in daily operation. Until now, there has been limited feedback on how various operating practices affect the Azipod® propulsor. Now it is possible to instruct the operator to perform various maneuvers so that the service interval can be maximized. Harsh operation practices can be smoothed while adding effect to inefficient practices. It is also possible to advise on, for example, barred speed ranges or combinations of various operational parameters, to minimize equipment wear. Passive and active vibration damping systems, which are developed and tested within the project, further increase the equipment lifetime in a very cost-effective manner.

Reliability can be increased by integrating the developed measurement system in the remote diagnostic system, which makes it possible to follow the operation remotely and react to eventual changes in system behavior. Now it is possible to develop remote diagnostics in a truly predictive direction.

Traditionally, condition monitoring is used to detect changes in system behavior as early as possible – a detected change indicates an initiated fault. However, once a fault is triggered, it usually develops and, at best, only the change of rate can be affected. The data analysis and system development carried out in S-STEP make it possible to advise the operator so that the initial fault is not triggered at all.

Further, with current technology, reliability issues cannot usually be traced back to operational data. In the future, for example, should a very unusual operation occur, it will be possible to evaluate the effect and plan accordingly.



Company impact

"The lifecycle cost can be reduced by utilizing the S-STEP data in daily operation. Until now, there has been limited feedback on how various operating practices affect the Azipod® propulsor. Now it is possible to instruct the operator to perform various maneuvers so that the service interval can be maximized."

Jari Toiva, R&D Manager/ABB Marine

Zero power sensor network

Background and objectives

Sensors have become ubiquitous in the monitoring, control, and automation of industrial processes. Wireless sensors play an increasingly important role because they make costly and often troublesome cable routing obsolete. In certain applications, it is desired that wireless sensors are also passive, meaning that they do not require a battery for their operation. Such cases include sensors installed in hazardous and/or limited-access environments (e.g., due to radiation, moving parts) or for monitoring processes that cannot be periodically stopped for battery replacements, such as in a nuclear power plant.

RFID technology has been on the market for years, and attempts are being made to apply it to wireless sensors. However, the need to accumulate energy from an RF signal to power the chip, handling A/D conversion and digital communication, limits the achievable reading distance to few meters at best. Integrated sensors enable some improvements, but also increase the complexity and cost of the tags.

Zero Power Sensor Network concept developed at VTT within DIMECC's EFFIMA program is an alternative approach, in which tags reflect an intermodulated signal, with frequency shifts corresponding to their sensor values. In this way, the A/D conversion is moved from the tag to the reader device. In addition, communication is analog, and thus reading distance can effectively be traded for resolution. The objective of this S-STEP research project was to build a demonstrator of the concept with a maximal reading distance exceeding the possibilities of RFID technology, preferably reaching beyond 10 meters, and to perform test measurements in both laboratory and industrial environments.

Results

During the DIMECC S-STEP program at VTT, the concept was refocused to accommodate the trade-off between reading distance and measurement resolution. Two versions of the control software evolved, and two separate reader devices have been built to implement them – one focusing on high precision and the other on long reading distance. The latter of these is being further developed in this project.

The processing of measurement data has been moved from the cloud to the local machine, thus removing the necessity for the reader to have access to the internet. At the same time, several new procedures for data handling and visualization of the results, as well as corresponding algorithms, have been written. The A/D conversion of the reader has been re-coded for increased speed and robustness.

A set of laboratory measurements have been conducted, showing that the reading distance increased from an initial 3.5 meters to 5 meters for the full sensor range, and up to 7.5 meters in the case of limited resolution. Additionally, a new method of reducing spurious noise in the measurements, and thus possibly further increasing the achievable reading distance, has been initially tested through mathematical calculations performed on the measurement data.

Impact The results achieved within this project affirmed the concept of Zero Power Sensor Networks a viable alternative to RFID whenever the measurement resolution can be traded for an increase in reading distance.



Project motivation and achievements

The mission and objective of S-STEP – to create industrial internet technologies that enable superior services for Finnish industry – has been at the core of Project 2: Advanced analysis, prediction, and reasoning. The main goal has been to enable new services based on deeper know-how about the equipment through advanced analysis methods. The market is changing, and this brings new challenges and needs for operation and maintenance. Better understanding about failure mechanisms and the development of new predictive diagnostic methods, as well as the improvement of maintenance practices, is therefore essential for cost-efficient lifetime management. At the moment, condition-based maintenance (CBM) systems are under development, and a large number of different sensor readings and parameters are continuously recorded in installations, in order to get a representation of the system states. The challenge is to keep the systems operating at an optimal point for any given conditions in real-time, including reliable diagnostics. Furthermore, the challenge is to have reliable and trustworthy data and automatic ways of analyzing and improving system performance, as well as optimized maintenance planning at the back office.

The research questions of the project were the following (see Figure 1).

1. What methods and tools should be used in addition to testing, to be able to assess the reliability of a product?
2. What information and methods are needed to predict changes in the condition of the equipment when it is in use?
3. How can all the data from tests, the remote monitoring system, and the maintenance database be combined and analyzed to get relevant reliability data in terms of optimizing availability, reliability, performance, and safety?

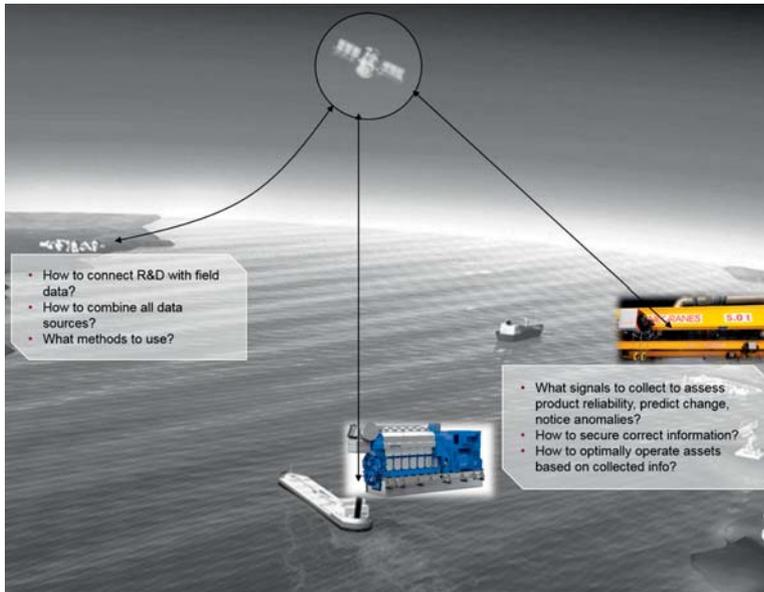


Figure 1. Research questions

We identified three thematic research areas, in which the research work was conducted in this project:

- 1) *diagnostics,*
- 2) *reliability and prognostics, and*
- 3) *collection, access, and interfaces to remote machinery data.*

Each of these aspects is described in a separate sub-section, with the key results and impacts. Before the thematic sections, we describe the two company showcases connected to these thematic sections that were implemented in S-STEP, as well as lessons learned from them.

Overall, the project has produced very valuable results. The advancements achieved are of great importance for future new services and product reliability. However, as the S-STEP program duration was reduced, the end results are not as mature as originally planned.

Some highlights of the main achievements of the project:

- Diagnostics methods and applicability to different areas; real-time as well as Big Data approaches to medium-speed engines
- Reliability analysis and prognostics of lifting devices
- Collection, access, and interfaces to remote machinery data, to enable analysis and component, system, and new service developments

CASE WÄRTSILÄ: Optimal asset operation and performance of industrial engines

Background and objective

The market is changing within the field of operation and maintenance. There are new challenges and needs for new technologies and services, including understanding about failure mechanisms and forecasting diagnostic methods.

Currently, engine diagnostics are mostly based on thresholds set to give an alarm or, in the most severe cases, to shut down. They do not, however, provide the information needed for daily operation and maintenance planning. One of the main goals of the project has been to develop reliable real-time diagnostics methods, and that can be linked to optimal asset operation. Furthermore, identification of what data is to be collected locally and remotely has been studied in order to enable development both of new services as well as of critical input to product development.

The long-term goal is to enable new services in maintenance practices; more reliable products in terms of safety, reliability, and availability; and better cost-efficient lifetime management.

Results

Overall, the focus of the university partners' inputs has been on developing diagnostics methodology, as well as data collection and interfaces. Wärtsilä has concentrated on the research work into a "black-box" technology for long-term diagnostics and reliability analysis, optimization of engine control under variable site conditions, and lastly, investigating new methods for alarm-based root cause diagnostics. The university partners' inputs have, in parallel, given excellent understanding of the feasibility of diagnostics methodologies for different parts of the engine. To be highlighted are real-time adaptive diagnostics methods on fuel systems, as well as the long-term follow-up of turbo-charging performance and maintenance needs.

Impact The work has been given excellent input, both in terms of what can be done and in terms of what challenges are faced.

Two solutions are highlighted as being close to industrialization: black-box and optimization for variable site conditions. However, advancements in diagnostic methods are equally important, and there is now a clear understanding of the challenges and limitations for different analysis methods and target system applicability.



Technical solutions

Reliability has, in many cases, the highest priority of all Wärtsilä customer requirements. An important part of developing reliability is the need for feedback data from field engines concerning running profile, usage, and fault information. Many Wärtsilä field engines already provide running data, but not in sufficient detail. Hence, a prototype “black-box” was produced, which collects “counters” such as running hours and high-frequency data before and after an engine shutdown event. The tests show good results for the first set of features with working counters and data export. A demo session for stakeholders also confirmed that the developed parts are well in line with expectations. The project is therefore proceeding with targeting real engine tests and developing prototype refinements.

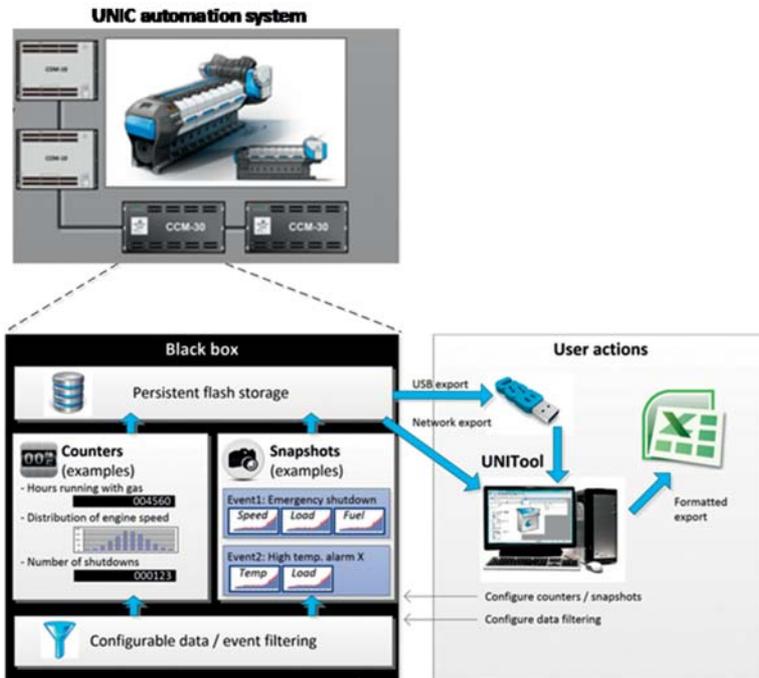


Figure 1. Black box architecture

Another important project highlight focuses on increasing engine output availability. As of now, engine output is reduced according to static rules like ambient temperature. For a customer, this means that an engine's maximum output might be reduced considerably under certain conditions. With increased awareness of engine condition, could the engine output instead be adjusted according to the actual condition of the engine? The main concept chosen to be tested was called “active load limitation”. This embeds a function in the control system that prevents

thermal overloading of the engine by monitoring predefined process data, and sets an appropriate maximum load. Prototype tests are still waiting for the right weather and safety conditions at a pilot customer site, but some successful turbo-speed limitation tests were conducted successfully. The overall function is expected to have a great impact on engine operation in certain conditions, and is an example of what can be achieved with increased condition awareness.

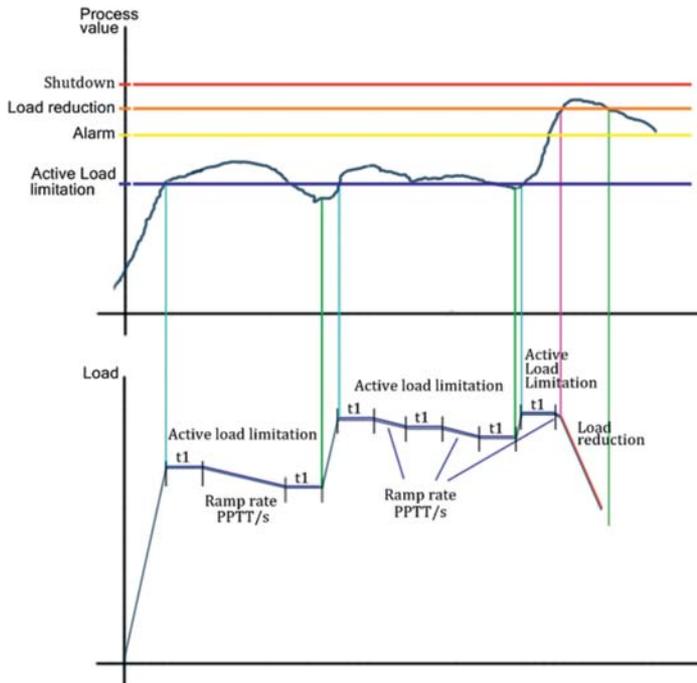


Figure 2. Active load limitation illustration

In addition to the above highlights, advances have been made in studying turbo-charging performance based on existing long-term CBM data. Furthermore, adaptive diagnostics methods have been developed, using injection systems as case study. These advances have greatly increased the knowledge of different diagnostic methods.

Lessons learned

The expectations for new services enabled by new industrial internet technologies are high. Several rapid advances have been made to start enabling such new services, like the black-box and optimized control techniques. On the other hand, there is still a road ahead for truly predictive maintenance techniques, and further development of diagnostics methods is clearly needed.



KONECRANES®

CASE KONECRANES: Reliability of lifting devices

Industrial need

The S-STEP P2 project at Konecranes was built on one main research topic: the reliability of a product. A crane as a product has to be extremely safe and have high availability in order to fulfill customer needs. High safety and availability can be achieved through successful product design and maintenance actions, which are defined during the development process. The development process requires guidance in reliability, and therefore Konecranes has its own department, Reliability Center (RC), to ensure and develop reliability. The P2 project goals were defined by RC to take Konecranes to a new level in design reliability of products and in utilizing field data for product development.

ADVANCED ANALYSIS, PREDICTION, AND REASONING

P2.2

Valtteri Peltoranta
Konecranes

The goals of the project were as follows:

- Enable thorough reliability assessment already in the new product development phase
- Develop suitable methods to detect condition changes in critical components during the crane's life-cycle
- Turn available usage, maintenance, and testing data into valuable new information by combining and analyzing it

Product reliability was chosen as the main topic for the following reasons: 1) to increase customer value through improved availability and safety of KC products, 2) to lead Konecranes more into the predictive maintenance business, and 3) to create new business opportunities by combining available field data using advanced analytics tools. A wire rope hoist was chosen as a showcase product for the project.

Results Overview

The P2 project brought several major achievements for Konecranes during its 2.5 years. Figure 1 shows the new additions (light green) to the reliability process, which was established during the project, together with the research partners (VTT and Novia UAS). In the following chapters, one showcase achievement from each research topic is presented.

New methods for reliability assessment

The first major improvement to the KC reliability process was finding a suitable method to analyze test results based on proven usage profiles from remote monitoring data. Konecranes is currently monitoring more than 10 000 lifting devices that send data about their usage, alarms, and faults. The usage varies widely, depending on the customer, and therefore the stresses of the components vary in the same way.

In S-STEP P2, the data was analyzed to create different usage profiles (heavy, moderate, minimal) so that the numeric test results could be translated into expected reliabilities of the components in the customer field. Doing such comparisons enables Konecranes to identify the risk points of the device in real customer use, and to estimate maintenance and spare-part needs of the product population through the life-cycle. VTT supported Konecranes in the project by studying and suggesting the new methods for reliability assessment.

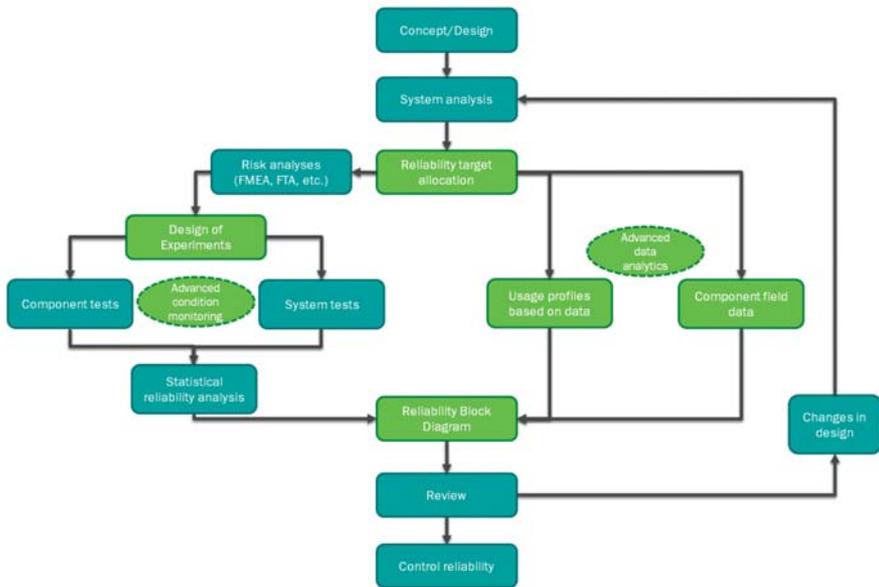


Figure 1. New additions (light green) to the Konecranes reliability process in the S-STEP P2 project

Figure 2 shows an example of how a component lifetime test result can be compared to the usage distribution based on remote monitoring data. The green curve presents the lifetime distribution of the component, and the black curve presents the expected usage distribution. The example is an electrical component that experiences hundreds of thousands of actuations during its lifetime. The right side of Figure 2 shows how the percentage of possibly failed components can be estimated based on the analysis.

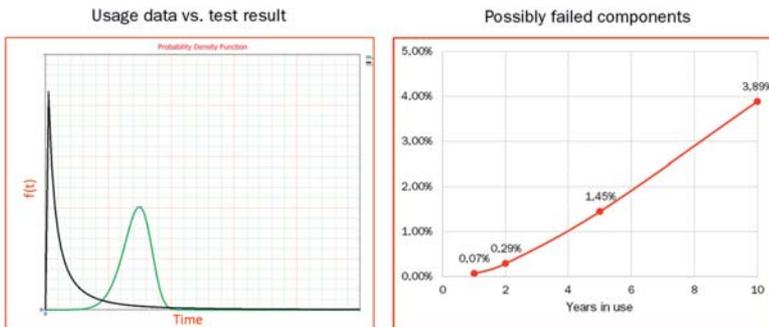


Figure 2. Usage distribution from remote data compared to component lifetime test result distribution (left) to predict percentage of possibly failed components (right)

New tools to predict condition changes of a lifting device

A significant improvement was also achieved in condition monitoring of lifting devices in the product development phase. An advanced condition monitoring system was built around the showcase hoist during the project, so that changes in critical components could be detected well before any functional problems appear. The system consisted of different sensors such as accelerometers, microphones, and a laser distance sensor. A design of experiments test (DoE) was conducted to give insight into how different usage profiles (load, starts, lifting speed) affect the condition of the device during its lifecycle.

The automated condition monitoring system revealed such changes in condition that have not been detected before. For example, the microphones detected changes in the condition of the rope reeving system, and the changes were identified using time/envelope domain and spectrum analyses. The study was conducted together with VTT, who had the main responsibility for analyzing the condition monitoring data. Similar automated monitoring system and analysis methods will be used in the lifetime testing of new products at Konecranes.

Combining and analyzing field data

Konecranes has been collecting different types of data from production, usage, and maintenance for several years. The achievements in the S-STEP project enabled Konecranes to combine and utilize different data types in new ways. The cooperation with Novia UAS generated, for example, a method of analyzing component lifetimes in the field, by combining the usage history of a crane with the maintenance history of each component. The new information enables Konecranes to improve the accuracy of the existing maintenance intervals, and to make corrective actions quickly if any unexpected reliability problems appear in the field. Figure 3 shows an example of a combined usage history (lifting hours) and maintenance history (periodic inspections, planned maintenance, and repairs) for a crane.

Impact Konecranes has gained a lot of new competence in the project, which will set it apart from the competitors. The improved reliability process will ensure the safety and availability of new Konecranes products in a systematic way, before they are launched on the markets. The improvements will make the product development process more efficient and faster, and will consolidate the position of Konecranes as a manufacturer of highly reliable products.

Moreover, the new ways of combining and analyzing field data have provided Konecranes with valuable insight into the relation between the product usage profile and maintenance needs. In addition, the new combined data creates new business potential by providing information about improvement possibilities for maintenance, and needs for new products or product improvements.

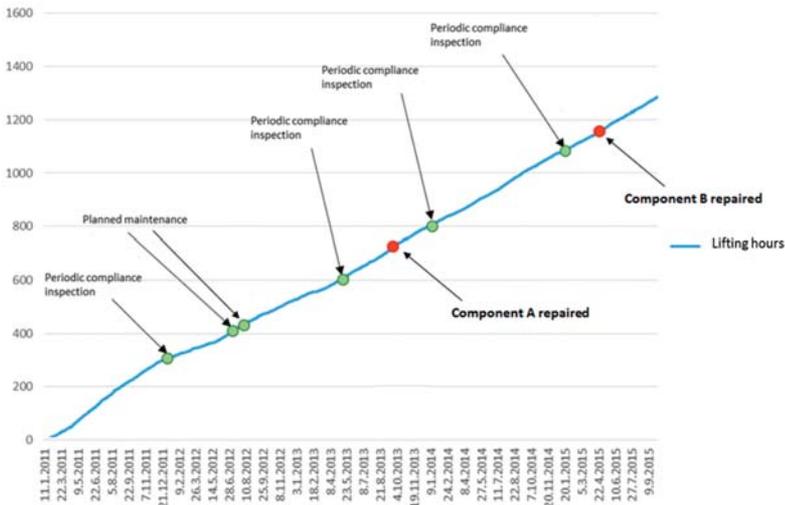


Figure 3. Combined usage and maintenance history data for a crane

Lessons learned

The project as a whole was successful for Konecranes, and the original targets were achieved in many respects. A key factor in the project was the frequent update meetings together with the research partners, VTT and Novia UAS, which kept cooperation on the right path.

It became clear during the project that not all the challenges related to the research topics could be solved within the project. However, the continuous improvement in the Design for Reliability (DfR) process and methods are a way to identify and diminish uncertainties in product reliability in such a way that the product meets the defined requirements. The new DfR process and methods, which were built in S-STEP, will be used when the next generation of lifting devices is developed. The achievements in the project are a cornerstone for successful new products and will keep Konecranes at the top in crane reliability and maintenance.

Tomi Krogerus/Tampere University of Technology

Kai Zenger/Aalto University

Jerker Björkvist/Åbo Akademi

Kendall Rutledge/Novia University of Applied Sciences

Diagnostics

Diagnostics research has been focused on studying and developing diagnostics methodologies for common rail systems of industrial engines, and learning methodologies associated with streaming power-plant data. In the following sections, this research is presented with key results and impacts.

Diagnostics of common rail fuel injection systems

The significance of the reliability and high availability of engine systems has been strongly emphasized during recent years. Given the challenges that we face with the sustainability of transportation energy, developing efficient, reliable, and flexible high-pressure fuel injection systems will have a significant impact on future engines, the transportation industry, and the fluid power sector. Diesel engine fuel injection plays an important role in the development of combustion in the engine cylinder. The fuel injection process consists of periodic events from hundreds of microseconds to a few milliseconds, which need to be precisely controlled and monitored continuously in order to run smoothly. Arguably the most influential component of the diesel engine is the fuel injection equipment. It has been shown to be the largest contributing factor to diesel engine failures. In order to meet increasingly stringent emissions regulations, and to satisfy growing demands in relation to economy and engine performance, precision injection timing and exact fuel quantity dosing have become key elements over the entire operational life of the engine. These goals are seriously affected by fuel quality and the contained particles, which often lead to more or less unpredictable wear of the parts [Marker 2015; Krogerus 2016].

In this research, common rail (CR) diesel fuel injection systems of industrial engines have been studied to develop diagnostics methods for these systems, and to achieve greater knowledge of the operation of these systems. Extracting the health information of components in the fuel injection system is a very demanding task. Besides the very time-consuming nature of experimental investigations, direct measurements are also limited to selected observation points. Diesel engine faults normally do not occur in a short timeframe. The modeling of typical engine

faults in a controlled manner is thus vital for the development of diesel engine diagnostics and fault detection. Simulation models based on physical grounds can enlarge the number of studied variables and can also obtain a better understanding of localized phenomena that affect the overall behavior of the system.

Developed simulation models and diagnostic methodology

Tampere University of Technology's CR rail system has been utilized in this research. For this system, a custom-made electronic control unit (ECU) was made to control rail pressure and the studied injector. This CR system and ECU has been used for measuring data for the verification of simulation models and the development of diagnostics methodologies.

A detailed simulation model of the studied injector, using GT-SUITE software, was created, and the model was verified successfully using experimental measurements made in the Tampere University of Technology laboratory. A simplified Matlab-Simulink model of the studied injector was also developed and verified against a much more detailed GT-SUITE model. The simplified model describes the phenomenon in the injector and the rail surprisingly well, and can be used in diagnostics research to study the features of the common rail system with modeled faults, especially when fast computational speed is essential and/or a more detailed model is not available.

Wärtsilä's CR system was modeled (rail and six injectors) using GT-SUITE software, and simulation results were compared to the measurements. The model can be used for studying the behavior of pressure changes in CR system and diagnostics research. This model also gives us information on the repeatability of pressure behavior in the case of several injectors. This information is vital for the development of diagnostics methods for this kind of system.

The knowledge gathered from a real common rail test system, shown in Figure 1, and corresponding simulation models were utilized to develop a method for diagnostics of injection events.



Figure 1. Common rail test system at Tampere University of Technology (TUT)

A method for the detection of relative duration of injections based on filtered rail pressure data was developed. The method enables adaptive control of the duration of injection events, so that finally the injected fuel volume would be the same as originally. In the method, the pressure signal during the injection is first normalized and filtered. After this, a derivative of the filtered signal is calculated. A change in the derivative of the filtered signal that is larger than a predefined threshold indicates an injection event that can be detected, and its relative duration can be identified as shown in Figure 2. Injection times between 500 μs and 750 μs were used in this research to simulate a drift in injection duration. The pressure level was 1400 bar. 100 injections for each different injection time were used, so 700 injection events were analyzed in total. The results show that the developed method can detect drifts in injection duration and also the magnitude of drift, which can be used for adaptive control of injection duration. Further testing and verification of this method with real engine data is still needed to fully validate the method.

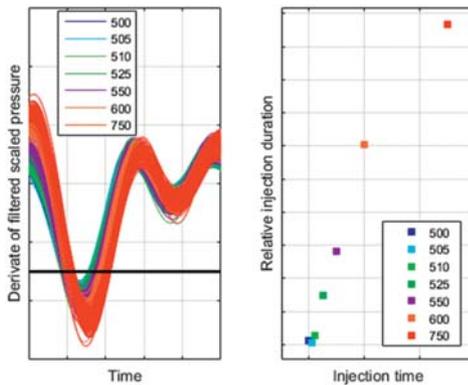


Figure 2. Detection of injection event and identification of relative duration

Methods based on frequency domain and statistical analysis

As another data-based approach, frequency domain techniques and statistical analysis were investigated. The target was to find suitable fault detection methods for actual implementation. Preferably, the methods were to be sufficiently simple to be comprehensible to the practicing engineer, at least principle level. During the research, it was found that the first-principles model-based approaches were quite difficult to apply, as they were highly system dependent and the dynamics of the common rail system contain several elements that cannot be modeled with modest mathematical effort. For these reasons, the main approach was to essentially find behavioral characteristics in the measurement

data, which could be used to detect anomalous behavior in the common rail system.

The data was obtained from an actual common rail test-bench located at Tampere University of Technology. Two main fault detection methods were applied to the common rail system, and their effectiveness was investigated through simulations and analysis of the measured data. The first method that was investigated was based on well-known Fourier-analysis techniques, which enable detection of the frequency content of a measured signal. The frequency-based approach was tested for detecting faults related to the high-pressure pump of the common rail system, and the approach proved to be feasible, especially due to the cyclic behavior of the pump.

Based largely on a simplified first-principles model found from the literature, a fault deteriorating the volumetric flow quantities of the pump was simulated, and the faulty behavior visible in simulations was translated approximately to the measurement data. It should be highlighted that these simulation results were not verified against a real faulty system, and this is something that should be pursued in future research. In the simulation, as well as in the measured data, over which faulty behavior was numerically superimposed, the frequency content of the signals clearly showed changed results in the expected frequencies.

The second approach investigated was based on forming a statistical model of an injection event. Using statistics, local mean value models were formed for injection events at different pressure levels, as well as at different injection times, and this was found to be a plausible method of picking out faults visible in the time domain behavior of the injections. A simulation model provided by Tampere University of Technology was used to inspect the possible effects of a clogged injector nozzle on the pressure behavior of the rail. A simple limit-checking method was compared to the results obtained from the simulation model, and was found to provide a simple and very understandable way of detecting injector deterioration. The injection-event measurement data, even though cluttered by the test-bench measurement noise, could be quite easily processed to enable reasonable statistical bounds for a faulty injection. As a supplementary result, a simple Fourier-series-based approximation was found quite efficient for tidying up the injection data from the high-pressure pump-induced oscillation.

Both investigated approaches can be very well scaled to cover a wide range of common rail injection systems and engine configurations. This is the inherent perk available, due to the loose assumptions required from the system. Should the fault detection scheme be based on a precise mathematical model of the system, the transformation of one common rail model to another could be an arduous task, due to the large number of configurational possibilities. As a downside to the approaches

presented, the data-based approaches use primarily local models of the system, and in application it should be carefully evaluated how many different operating points are to be used, and whether interpolation could be used between the operating points.

Proposed subsequent actions include taking the presented methods and applying them to a system that would then be modified to produce faulty behavior. This could be done naturally by using actual faulty equipment, but the possibility of modifying equipment to produce seemingly faulty behavior compared to the initial system should also be considered. This type of testing is considered highly important, as there was no possibility to test the presented methods on an actual faulty system during the work.

Diagnostics methodology for CR systems

Commonly, core diagnostics systems are implemented using alarm thresholds on direct sensor readings. That is, when a temperature reaches a threshold value, an alarm is triggered, and the plant operator has to react to this alarm. The action on an alarm might range from silently acknowledging the alarm to performing a full stop on the plant. The alarm can also be false alarm, due to sensor failures, leading to unnecessary downtime.

The objective of the task of diagnostics methodology was to reach a new level of automation for diagnostics. As a test subsystem, the CR system was used, with the objective of exploring model-based diagnostics methodology. A model of the subsystems is built, describing relevant relationships between physical variables in the system. When sensor data is combined with the model, residuals can be calculated, expressing the level of inconsistency in the system. Using the static or dynamic behavior of the residual, the new level of diagnostics can be applied.

In order to explore the possibilities of this methodology, a simplified version of a CR system was built. The model was based on the mass balance of a CR system, with inflow (common rail pressure control system and pumps) and outflow valves (injectors) (see Figure 3).

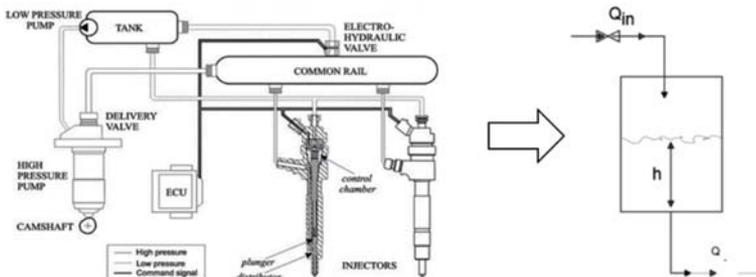


Figure 3. Simplified model of CR system for diagnostics purposes

When the simplified model is compared to the actual model (Figure 4), the residual is calculated and can be used for a further fault decision, based on static and dynamic behavior. The fault decision can be based on several criteria, such as thresholds, trends, and probability functions.

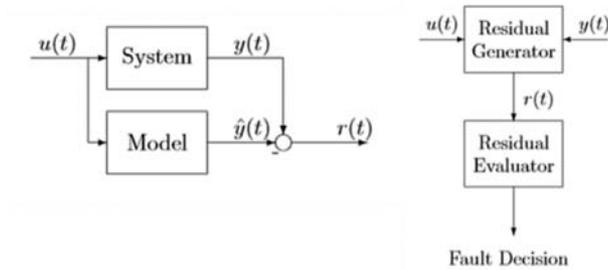


Figure 4. Fault decision based on residual from model

In order to verify the usability of the methodology, the system was simulated using a Simulink model of the actual system. Hence, there was a need for a detailed model of the actual system, and a simplified version for the diagnostics system. For the detailed version, we could use knowledge from both Aalto University, on detailed injector modeling, and Tampere University of Technology, on real dynamic behavior in CR systems.

Conclusions:

- Model-based diagnostics gives a straightforward new level of information
- Model construction is, however, not always straightforward – what is a suitable level of detail in order to work efficiently?
- Residual analysis needs additional effort

Adaptive diagnostics

One challenge in real systems is that they are always a specific implementation of the general system. The specific system has different levels of offsets for assumed physical properties: sensor reading offsets, offsets in pipe dimensions, variations in ambient conditions (temperatures, humidity, fuel quality, etc.), leading to a need for automated parameter estimation for the running plant. The diagnostics system needs to be adaptive; it should learn what the “normal” residuals are in the system, but should react to residuals that are relevant for diagnostics. Hence, a general research question here is: *When to adapt and when to signal a fault?*

In order to move toward automated diagnostics, an analysis of data-driven methodologies was performed. The assumption was that data-driven methods could provide possibilities for automated adaptive diagnostics. Data-driven fault diagnostics can be performed on both direct measurements and model residuals. Using data-driven methods, features such as data compression, distribution analysis, transitions analysis, and adaptiveness can be performed.

One challenge when dealing with the data provided from the plant is the huge amount of data available, and the need for methods for finding anomalies in data sets. One method studied was Symbolic Aggregate approximation (SAX). SAX divides time series data sets into segments and symbols, and hence makes it easier to automate the detection of trends, outliers, and syndromes. Figure 5 shows the feature of discretized symbols using SAX, which can then be used in a transition matrix and a histogram. Hence normal transitions can be identified, whereas new ones can be identified and marked as either faults or alerts to an operator.

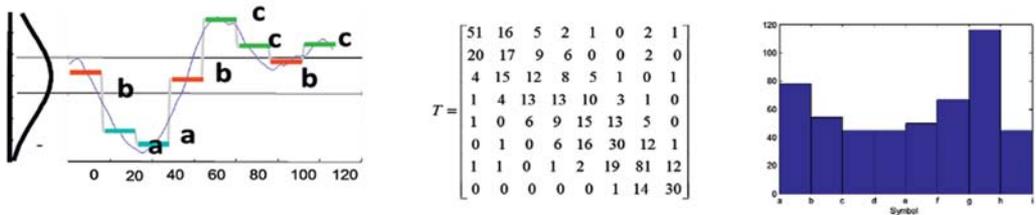


Figure 5. Discretized data representation using SAX, transition matrix, and histogram

A challenge with the SAX method is to automate the needed parameters: symbol levels, alphabetic character size, window lengths. However, we believe that this can be rather subsystem specific. For instance, a CR system can use one set of parameters, whereas a cooling subsystem needs another set of parameters.

Conclusions:

- Novel time-series analysis methods give new possibilities for automated diagnostics, which could be included in future diagnostic systems
- Adaptation of time-series analysis methods to real systems, however, still requires quite a lot of manual engineering work, but this will change in the future.

Impacts of CR research

CR research has several important impacts on the manufacturer, end-user, to research and environment. These are as follows:

- State-of-the-art diagnostic methods and simulation models of CR systems, especially CR injectors
- Engine longevity facilitated by consistent operating conditions throughout the life of the unit (e.g. consistent power output and consumption) → balanced engine loading / reduced wear
- Injection system reliability → engine reliability
- Longer injector life / injector exchange intervals before wear limits are reached
- Enables On-Board Diagnostics (OBD) of injectors (e.g. injector failure, drift, wear status)
- Enables creation of CBM services related to CR systems

Learning from streaming power-plant data

With the goal of characterizing and identifying normal and anomalous system states of operating engines, we utilized a time-dependent graphical model framework. The analysis framework was tested with components from Wärtsilä's condition-based monitoring (CBM) data archive, which is operated to digitize and manage performance and operational variables for gensets within power plants. The CBM system operates on thousands of variables from multiple gensets within a power plant. For a medium-sized plant, the data quantity may be in the order of 500 Mbytes per day. Such scenarios are examples of streaming data. The conceptual definition of streaming data is that its analysis cannot fit into a computer's memory, and its generation is continuous. The goal of the work described here is to learn from the streaming power-plant data to identify anomalous system events and also to characterize normal system behavior.

We implemented the framework for assessing system anomalies using relationships between variables instead of the variables themselves. By doing so, the data dimensions of the analyses are dramatically reduced, making the problem tractable. The new analysis uses concepts from graph theory to efficiently describe the change of interrelationships between variables through time. We produce streams of graphs that have vertices representing variables within the engine system, and edges that represent the correlation structure between variables.

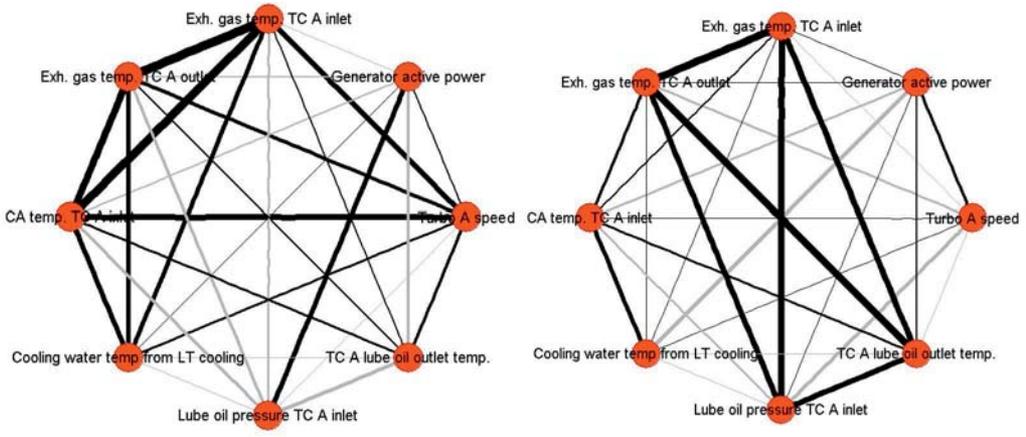


Figure 6. Example correlation structure graphs from dynamic graph analysis from an engine subsystem. Before (left) and after (right) system change graphs are presented. The Bayesian change-point detection method identified transition times (not shown). The correlation matrices are presented by thickness (correlation magnitude) and color (grey: negative; black: positive)

By applying change detection algorithms, the stream of graphs may be partitioned into segments representing periods with a homogeneous parameter state within segments and change-points at the segment boundaries. Figure 6 shows representative graphs from separate homogeneous segments. The change in system state is clearly represented by the change in the correlation structure.

The present work demonstrated proof-of-concept by developing methods and experience utilizing streaming graphs. To mature this technology, the identification of optimal change point analysis methods for the engine data is required. Additionally, the concept of system drift, in which system parameters change slowly over time, needs to be addressed to help characterize the behavior of an aging system. We expect that future engine control rooms will require variants of the techniques described here.

Reliability and prognostics

Reliability and prognostics research has been focused on studying and developing methodologies for lifting devices and marine engines. In the following sections, this research is presented with key results and impacts.

Investigating the effects of operating profiles on engine reliability

In this study, operating profiles of ships and their usage scenarios were investigated. An MSc thesis was done in this research area. A summary of this thesis is presented here. The target of the thesis was to find an efficient way of working or a method that could be used to study the relationship between diesel engine wear and the operating profile of a certain dredger vessel. In this thesis, operating profiles of dredger vessels, as well as engines and their usage scenarios, were investigated.

The thesis covered:

- the Wärtsilä 26 diesel engine and its functions
- the basics of reliability engineering
- the system reliability analysis (Figure 1)
- one named dredger and its functions (Figure 2)

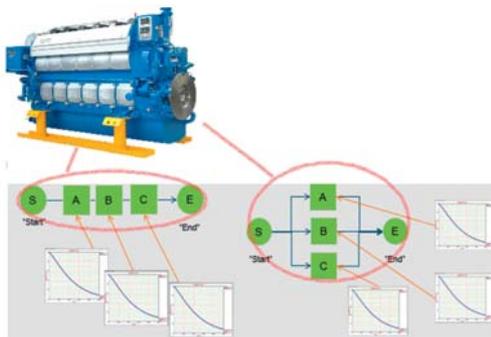


Figure 1. The system reliability analysis of the engine

The data logger configuration tool was used to collect the sensor data from the Wärtsilä 26 engines. The thesis focused more on the way of working, because only limited operating data was available. The operating data was from a 2-week period.



- 1) The draghead do the actual work by milling and sucking the soil material from the sea bed while the dredger is sailing.
- 2) Suction pipes, a large centrifugal pumps transports the soil from the sea bed to the dredgers hopper.
- 3) The hopper in Marianne dredger is lokated between the accommodation deck and engine room.
- 4) The bottom doors which can discharge the dredged material or soil directly into the sea.
- 5) The rainbow nozzle which enables emptying the sea bed material onto a shore.

Figure 2. Trailing suction hopper dredger

The engine data was collected from three Wärtsilä six-cylinder in-line 26 engines, which are located in one named dredger vessel (Marianne). Two of the engines are for propulsion use, and one is for dredge pump use (Figure 3). The dredge pump engine (DPE) power output is slightly de-rated in order for the engine to be capable of operating with constant torque in a speed range of 80 to 100% of the rated speed.

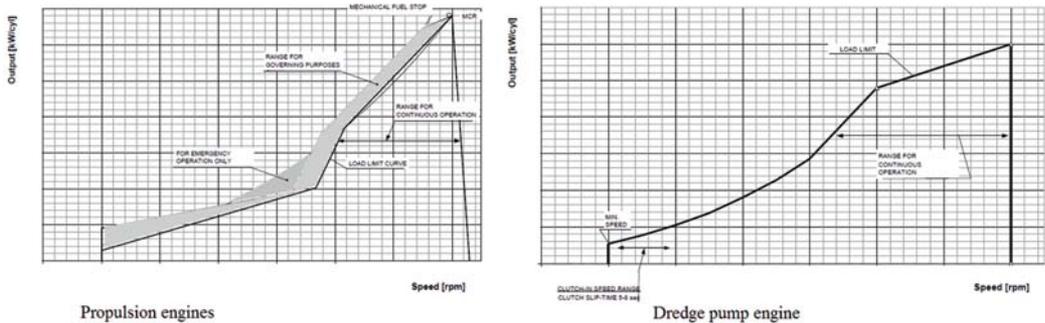


Figure 3. The operating field for propulsion (controllable pitch propulsion, CPP) (left) and dredge pump engines (right)

Depending on the dredger's operating modes, the main engines can be operated in many ways. However, the main purpose of the port side and starboard (SB) side engines is to produce propulsion power for the dredger via reduction gears.

The collected data from 2 weeks of logging was analyzed with the focus on the following:

Number of cold, warm, and hot engine starts

It was noted that the DPE engine had been started 99 times during the 2-week period.

Load and speed distribution

It was observed that the DPE was running at a low speed 67% and on a low load 87% of the total engine running hours.

Number of alarms, shutdowns, and load reductions

The most prominent finding was that the SB engine's fuel-oil inlet pressure had been too low 259 times during a 2-week period.

Sudden load changes

The DPE was found to have a lot of big load changes compared to other engines in general. Instant load steps up to 60% of full load have been found from logging data. However, the analysis is still ongoing.

The conclusion part is still in progress. However, besides useful information on the dredger's engine functions being obtained, it will need more research in the future to get better understanding of the engine component wear when dredger engines are operated at a certain load.

Reliability modeling approaches for lifting devices, and tools for predicting changes in the condition of lifting devices

The target of this research activity was to provide tools for a showcase hoist in relation to Konecranes' reliability and diagnostics requirements. In hoist reliability, approaches to allocating reliability requirements identified for a new product, down to reliability targets for individual sub-systems and components, were surveyed. Modeling approaches to support systematic evaluation of the reliability evidence and data generated at sub-system and component levels, with respect to the reliability and availability performance requirements, were set for the overall product. These we reported as methods and tools for assessing the reliability of a lifting device in terms of safety and availability.

Subsequently, the identified reliability modeling and allocation approaches were evaluated. Special attention was given to how the numerical reliability targets (safety/availability target integration) set for a new product should be allocated to different components/subsystems, and how uncertainty related to component reliability values can be handled. The target is to develop a proposal on how hoist reliability tests should be developed in order to correlate better with field performance, and to identify how results could benefit the customer-specific maintenance service-offering definition. The results of this research activity were used

in the improvement of Konecranes' reliability process (see Konecranes Case: Reliability of lifting devices).

In hoist diagnostics, Konecranes constructed a test setup for selected hoists and conducted a test program for them. The test program was divided into functional testing and lifetime testing. Functional testing is used for special testing, mainly related to the different operational cases, which are expected to bring benefit for the hoist reliability analyses and management. Functional testing results were partly used to evaluate how the measurements from the other ongoing tests are carried through and cross-connected as noise. Special attention was given to the orientation of the microphones.

Each hoist in lifetime testing was instrumented with three vibration acceleration sensors, to monitor the condition of critical components such as gears and bearings, and with two microphones, one on the upper sheave and one on the hook. Since gear and bearing analysis requires knowledge of exact rotation speed, for example for impact frequency and harmonics, gear mesh, and sideband analysis, the hoist's primary shaft rotation was measured. In addition, temperature and hook position were measured. The measurements were synchronized with hoist operation so that the circumstances were standardized during each measurement. Sampling duration was adjusted to collect a relevant amount of information, namely an adequate number of shaft full rotations. The measurement sampling frequency was 20 kHz. However, certain non-dynamic process parameters were sampled with a lower sampling frequency.

Our main research target is to develop valid tools and methods for the identification and prediction of failures or changes in operation, based on Konecranes' hoist lifetime testing and measurements, and to gain new knowledge on hoist operation and maintenance management in the field. In the course of this process, several parameters and analysis methods, such as vibration acceleration envelope analysis at natural frequencies, energy ratio, zero-order figure of merit, and spectrograms, were applied for each measurement, and the results of these were evaluated and reported as a function of cumulative test time. Some findings are reported in Konecranes' showcase chapter, for predicting hoist condition changes. The work is still ongoing.

Improving maintenance of cranes using advanced data analysis

We are working toward improving maintenance and product development of Konecranes cranes by developing a process to identify different usage profiles in a large population. Cranes are operated in numerous ways, even when the design limits are defined based on a limited number

of usage classes. Analysis of remote monitoring data of cranes enables a grouping of the field-deployed hoists based on how the hoists are actually used. Figure 4 shows an example of such an analysis, in which 10 use characteristics and 24000 hoist-day combinations were grouped. A hoist-day is a time dependent collection of usage characteristics for an individual hoist over a full day cycle. This initial step involves two independent cluster analyses and a summary of their result interaction.

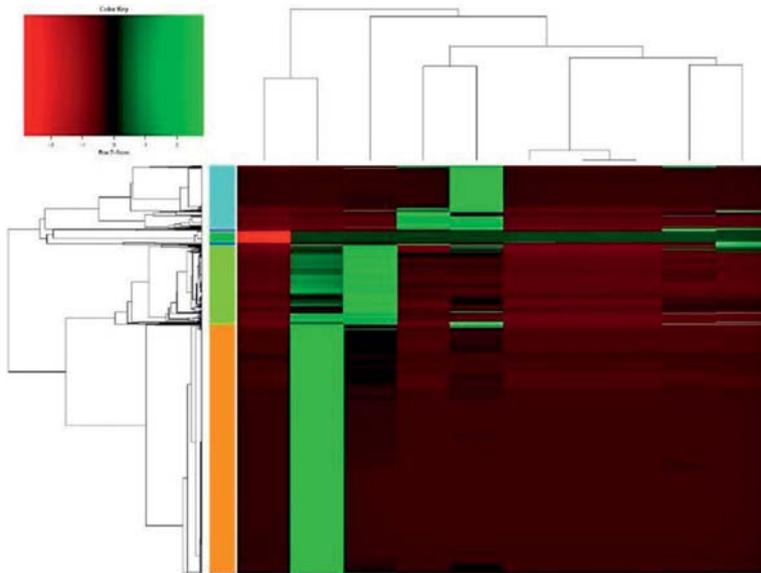


Figure 4. Using classification of hoist usage variables (top dendrogram) and hoist-day (side dendrogram) to identify features important to the organization of the field-deployed systems. Within the heat matrix, scaled parameter magnitudes are denoted by color (red = low values, green = high values, black represents the variable mean values)

This technique puts the focus on which usage characteristics are important in shaping the clusters of hoist-days. Presently, this work concerns identifying optimal classification methods that perform hoist clustering and that de-emphasize the temporal component of the hoist-day clusters. Different time summary periods and statistical distribution shape characteristics of the use parameters are under consideration.

The identified hoist clusters will also be analyzed in relation to the crane maintenance data. Understanding the interdependency between the real usage profile and the needed maintenance activities will help Konecranes to improve their tailored maintenance programs for cranes. The method being used here is analogous to applying statistical process control concepts to Konecranes maintenance services and product development. This work is continuing.

Collection, access, and interfaces to remote machinery data

The methodologies studied and developed in Project 2: Advanced analysis, prediction, and reasoning are heavily dependent on reliable, accurate (real-time) data. Therefore, in addition to the development of analytics solutions, the development of data collection, access, and interfaces to remote machinery data is an extremely important aspect that it is necessary to take into account in daily operations in the future service business.

The concept of Big Data

The amount of remotely collected data is rapidly increasing, and different IoT applications have made it easy to collect continuously a huge amount of data from sites located around the world. The challenges and opportunities provided by this huge amount of data are often referred to as the concept of Big Data.

In addition to reliable communication in the data-collection system, storing the data is a challenge. By using Wärtsilä as a case study, we compared traditional relational database systems to the newer Big Data management systems. The former rely on structured and the latter on non-structured data storage. It may take some time to find the required particular information from the huge amount of collected data. If the information is required in real time, the time it takes to search for and compute it might be critical. On the other hand, a huge amount of data enables remarkable improvements to the current utilization of data, and completely new types of services. Different control algorithms in the automation systems can be improved, and new types of control solutions can be developed. Currently, the annual machine service is mainly based on the operating hours of the machine, and service based on need is usually offered only if something breaks down and the need is urgent. Since IoT solutions enable more precise and efficient machine condition monitoring, the annual service can also be based on machine condition, so that

the need for different service operations is evaluated based on the condition of that particular machine, which is indicated by the measurements, not only by the operating hours. A huge amount of monitoring data can also make it possible to develop new types of services that can be offered to the customer. These types of new services will be one of the continuous R&D topics related to the Industrial Internet and IoT.

Asset management system

A second part of this case study was the interfacing of Wärtsilä's remotely collected data to their different users. The work started by interviewing different experts from the different positions in the company (R&D, marketing, etc.) to figure out what kind of data they need and what kind of tools they use to process and visualize the data. Then the design of the interface between the collected data storage and the asset management system was made based on this information.

One important part of the interfacing was the design, coding, and implementation of a software tool that enables performance queries and extraction of data from the data storage system directly to Matlab. The data is extracted in such a format that it can be further processed in Matlab without any additional conversions. This is an important property for R&D, because Matlab is widely used in the industry.

The main deliverables of this case study were the design of a new remote data user interface for Wärtsilä's asset management system, and the interfacing of Matlab with the remote site data. Moreover, some suggestions and recommendations for remote data interfacing are also given. The main results are published as a MSc Thesis [Xue 2015].

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Company impact

“The expectations for new services enabled by new industrial internet technologies are high. Several rapid advances have been made in S-STEP to start enabling such new services, like the black-box and optimized control techniques. On the other hand, there is still a road ahead for truly predictive maintenance techniques, and further development of diagnostics methods is clearly needed.”

*Jonatan Rösgrén, Program manager, Research & Technology Programs
Wärtsilä*



Company impact

“The S-STEP project as a whole was successful for Konecranes, and the original targets were achieved in many respects. A key factor in the project was the frequent update meetings together with the research partners. The achievements in the project are a cornerstone for successful new products and will keep Konecranes at the top in crane reliability and maintenance.”

*Valteri Peltoranta, Reliability Engineer
Konecranes*

Project motivation and achievements

The main objective of Project 3 was to design and pilot an open, extensible, and secure service framework as needed to integrate different plant information systems and fully leverage the benefits of modeling, simulation, and optimization. This is considered to be a prerequisite for further development of services on the so-called industrial Internet in a way that also enables the agility to move between different types of plant deliveries and company networks.

The above goal was further broken down into sub-goals, as listed below. The main achievements are summarized under each sub-goal.

- 1) Design an open and extensible software architecture that gives uniform access to different plant information systems, and implement a demonstrator for operation and maintenance work using the designed architecture. In the architecture, international standards like IEC 62541 (OPC UA) are utilized as far as possible.

Main achievements: Specification of the mapping of the CAE information model (Proteus/Dexpi) to the OPC Unified Architecture data model was done and tested with a prototype implementation. The work will continue after the S-STEP program, together with the OPC Foundation and the German Dexpi group, by formally creating an OPC UA companion specification out of this work (international standard).

- 2) Study and develop simulation-based prediction methods and tools in order to, for example, produce an advisory toolset for the operator, for more efficient operation of the process. The aim is to integrate first principle dynamic simulation models in parallel with the real process for getting better predictions.

Main achievements: A laboratory environment with real process equipment and a parallel virtual model was set up to study the methods for online predictive simulation. On one hand, the predictive simulation architecture was studied by developing a working prototype,

and on the other hand, the prediction methods and toolbox were developed. Four scientific publications were published and one is still under review. The work on applying the prediction toolbox to a real industrial process has started.

- 3) Develop methods and tools for better validation and verification of automation solutions. These methods include test automation, dynamic simulation-aided testing, and formal methods.

Main achievements: Specification of the needs and requirements for a simulation-aided control system testing environment was done. A prototype was implemented using a real industrial-strength automation project as a case example. The work has been documented in two Master of Science theses and two scientific publications (with one still under review).

- 4) Design and implement a real-time multi-level optimization production scheduling system where production scheduling is done continuously.

Main achievements: Specification, analysis, and proof of concept of a cloud-based production planning and scheduling system designed for the sheet metal manufacturing context. The work has been published in journal publications, and industrial implementation is in progress.

A more detailed description of the results of Project 3 is written in the following pages, starting with the showcases of Outotec and Prima Power, and ending with a description of the predictive online simulation.

Simulation-aided automation testing

Motivation

Outotec designs and delivers state-of-the-art processing equipment and optimized processes, including intelligent automation and control systems, as well as complete plants for the mining industry, metals processing, renewable energy production, and industrial water treatment. Fast and reliable ramp-up combined with long-term operation and maintenance services ensure that customers receive the best return on their investments.

One essential part of fast and reliable ramp-up is the commissioning, testing, and tuning of the automation system. Traditionally, this work is done mostly on-site. With complex plants, this ramp-up period can take up to 6–12 months. During the ramp-up, the production plant does not typically work at full design capacity, so the revenues to the plant owner are lower than with normal production.

With virtual commissioning, the ramp-up time for a real facility can be substantially shortened, because most of the time-consuming steps can be done in advance. In virtual commissioning system setup, testing and tuning are done against simulated production, and in an ideal case a fully tested system is just plugged into the real plant, and full production starts in days compared to months.

Other advantages with virtual commissioning are:

- Virtual acceptance tests, meaning that the same tests that will be performed on a real system can be done, and possible faults can be corrected well in advance
- Testing with a virtual plant can expose some process design problems that can still be fixed at a low cost
- It is possible to perform tests that are impossible or too expensive to do with a real system

- Automation software is more ready when moving to the real plant (traditionally, some part of the programming has been done on-site)
- In virtual commissioning, the best experts can easily be involved in the process, compared to commissioning on-site, where a poor automation engineer is left alone
- Bug fixing in the office, where there is no production pressure, gives better quality results

Summary In the S-STEP program, we developed a testing platform for simulation-aided automation testing. The testing platform comprehends all the functions from requirement specification to the final test report.

The core of the platform is a process simulation model that contains a mathematical representation of the real system, and has the same inputs and outputs to/from automation as the real system. The real process control system is connected to the simulation model using the OPC UA server, and in an ideal case, the control system can be connected to simulation and production environments without any changes.

Requirements for a complete manufacturing plant or process area are typically spread across multiple documents. The first challenge is to identify and find all related material. Good sources are the agreements between the plant provider and the customer, safety study results (like HAZOP documents), process and automation descriptions, process flow and P&I diagrams, loop lists and descriptions, and finally operator and maintenance manuals.

Once all the requirements are gathered, the next task is to move all the requirements to the platform in a unique format, so that the requirements can be processed. This is the most risky phase in the whole chain. Since many of the requirements are written only in free text format, there is always the chance of a misunderstanding.

In practice, it is not cost-effectively possible to test all the use scenarios for the plant. Based on the requirements, the test engineer selects use cases to be tested, and creates test scenarios for selected use cases. One test scenario includes the initial state of the plant and testing steps, such as an operator sequence, a transient in the process, or a fault scenario.

In final step, the test scenarios are executed with an experimental controller. The experimental controller can manage multiple test scenarios, so it is possible to leave the system running independently without continuous monitoring. While running the test scenarios, test monitors supervise that there are no violations against the requirements. If the test monitor detects a violation, it creates a detailed report of the problem and the scenario is tagged as "violated". The experimental

controller creates a test report on all performed tests, and from the test summary, the test engineer can easily identify the tests that were not passed. From the detailed reports, the engineer can find out what requirement was violated and what the process behavior was at the moment of violation. If necessary, the engineer can then re-run the same test(s) and watch the behavior of the system more closely. The same test(s) can be executed again after the problem is fixed, to verify that the correction works as planned.

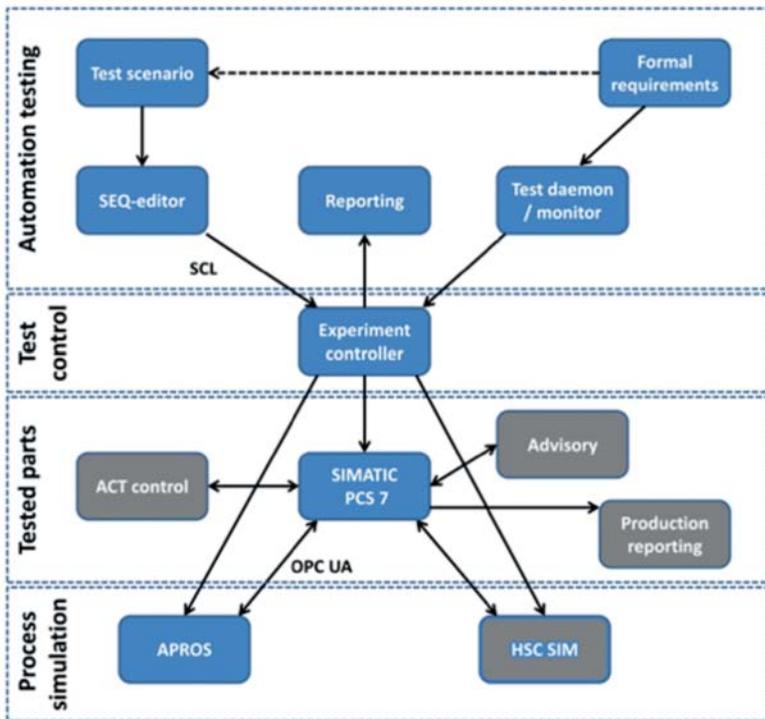


Figure 1. Simulation-aided automation testing architecture

Results All the components in the simulation-aided automation testing architecture (see Figure 1) were implemented, and the whole concept was tested with selected requirements and a few test scenarios. A simulation model of a pressure leaching process was built (see Figure 2), and a Siemens PCS7 process control system with real control software was connected to the model. Some minor changes to the software were required, mainly because the process used in this exercise was only a small part of a larger system. Requirements were collected from the real project documentation, and they were modeled into the system using linear temporal logic (LTL), and finally the test scenarios were planned and modeled (see Figure 3).

This study proves that it is possible to manage requirements in a formal way and to test the process control system against the process simulator way ahead of the real commissioning on-site.

However, there are lots of open questions before the platform can be put into everyday practice in process automation deliveries. The bottleneck is no longer the software or hardware capacities, but clearly the person-hours and skills needed. Some of the main challenges are:

- Easy requirement modeling
 - Linear temporal logic is too complicated.
 - When writing the paper, we are testing graphical programming using function blocks, which would be a more familiar method for the control engineers.
- A graphical user interface to manage and orchestrate the whole process
- The amount of work to create the simulation model can, in many cases, be too much.
 - If the model can be used for other purposes, such as system design, operator training, or PID tuning, that lowers the threshold.
 - Can a simplified model be used in some cases?
 - We are also studying the possibility to auto-generate the process simulation model from the other engineering material.
- Test speed. Due to the limitations of the process control system, the test runs were executed at real-time speed. This limits heavily the number of tests that can be performed
 - How to utilize parallel test runs
 - What if the process control is also “converted” into the simulation environment?
- Changes to the way of working in process control system deliveries
 - The target should be that a 100% ready and tested control system is available at the moment the plant is mechanically ready to be started. This makes deadlines earlier and brings the automation delivery process closer to the software processes.
- How to model and manage real work phenomena in a virtual test environment
 - Use of stochastics elements in simulation?

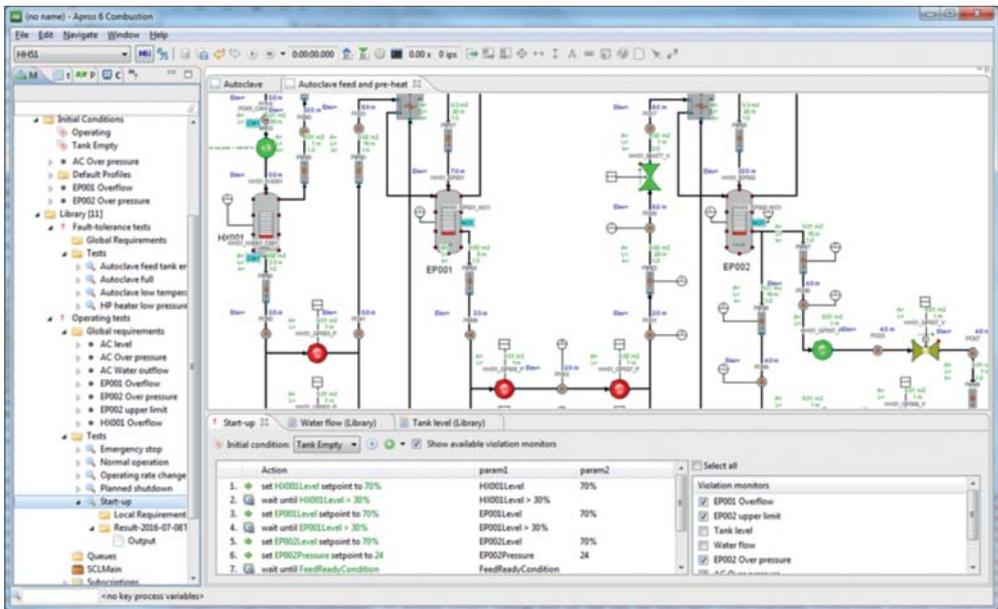


Figure 2. Test environment

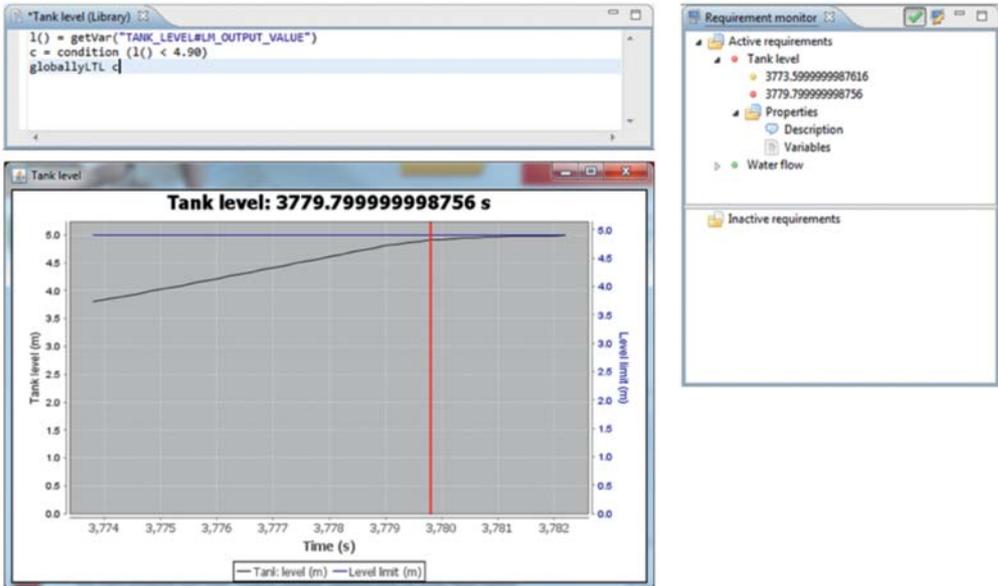


Figure 3. Requirements and monitoring test results

CASE PRIMA POWER: Cloud-based O&M optimization

Background and objective

Sheet-metal processing has some special characteristics in terms of production, from dynamic design to customized fabrication. For sheet-metal processing industries, it is critical to provide services that meet customers' specific requirements and tolerances. Many of the decisions are made several times a day, and analytic techniques such as mathematical optimization in material use planning are widely used in nesting problems. Mathematical optimization has great potential in this area, as computational performance is available in the cloud.

Results

This project has developed and piloted a concept of cloud manufacturing from three cloud-based solutions, namely CloudMES (manufacturing execution systems), and CloudPPC (production planning and control). The 'cloud' infrastructure is a projection of the supporting architecture for an integration of a 'mixed-reality environment', a 'real-time management business model', and a 'communication channel for collaborative management'. As shown in Figure 1, it consists of three layers: a presentation layer, a business layer, and a data layer.

Framework for optimization

Production process optimization is one of the most widely investigated topics in the field of manufacturing (Chandrasekaran et al., 2013). Formally, the process of optimization in manufacturing engineering consists of the following processes: (i) defining variables, constraints, and objective function(s), (ii) solving the constrained problem of general mathematical form using various types of algorithms and methods, and (iii) simulating the optimization algorithm and then deploying the algorithm in practical systems for application (Tao et al., 2015). Different types of optimization can be employed, due to the different nature of the formulated manufacturing problems. In this project, optimization tasks were identified in the line specification phase, design process, production planning process, and execution processes. The overall framework was implemented, and several items were piloted with real data (Figure 2).

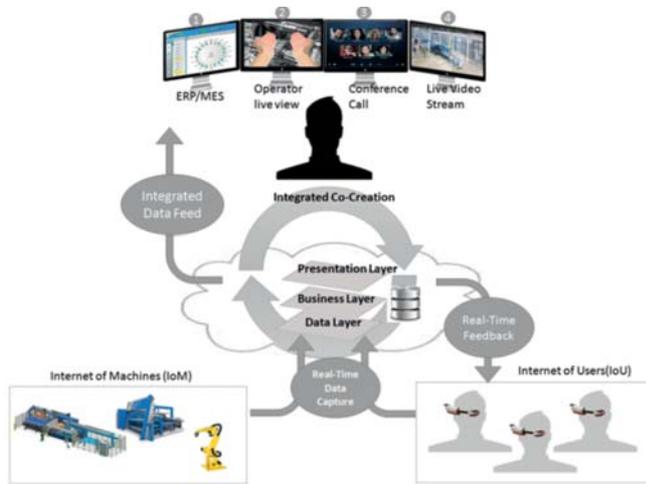


Figure 1. Overall system architecture for implementation

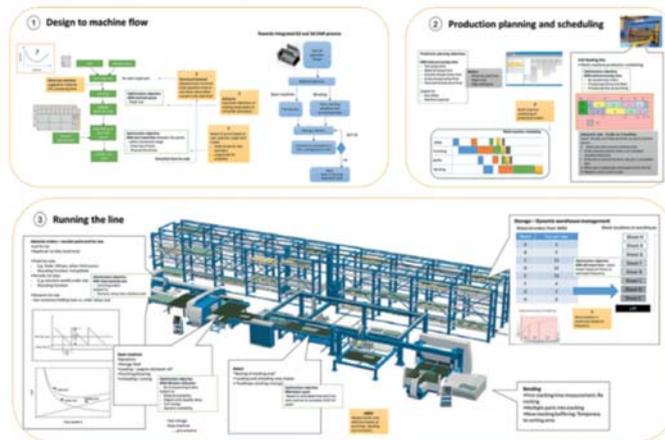


Figure 2. Optimization framework in a sheet-metal factory

CloudPPC: Cloud-based scheduling

We have implemented a cloud-based production planning and scheduling service that enables some features of cloud manufacturing.

Production planning and control (PPC) is critical for manufacturing execution. It includes the tasks of job or task scheduling, inventory planning, loading production, process selection and planning, facility location, estimating quantity and costs of production, capacity planning, line planning, follow-up, and execution. In the context of the cloud, a manufacturing environment, PPC, is even more difficult and complex. There are two main considerations:

- (1) Temporality of delivery configuration – The cloud manufacturing mode is driven by the uncertainty of customer orders.
- (2) Networked manufacturing – A single process includes multiple participants (i.e. cloud services providers and users), distributed resources, and decentralized management.

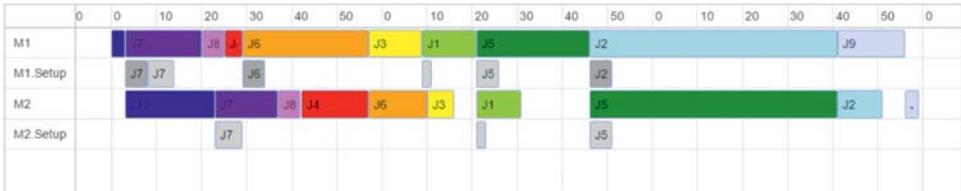


Figure 3. Generated production plan



Figure 4. Touch-based large-scale user interfaces for managing the production planning and execution process

Impacts A new smart manufacturing model, cloud manufacturing, has been proposed to fulfil the requirements of networked and dispersed production in sheet-metal manufacturing. The cloud provides a collaborative environment that can give people who manage sheet-metal manufacturing agility, more transparency, and empowerment through more effective collaboration.

In reality, cloud manufacturing is implemented using different cloud-based solutions to fulfil different functional requirements and business objectives. The potential benefits of cloud manufacturing are in operational efficiency. In the short term, all the partner factories and actors can utilize collaboration and communicate with others at distributed locations. In this collaboration system, distributed manufacturing activities can be integrated by standard regulations, and all the partners are verified. In the long run, cloud manufacturing also improves service provision and enhances the user experience. Services such as remote training, guidance, and remote assistance ultimately improve the user experience and lower the maintenance costs.

Predictive online simulation for the process industry

Motivation

Beyond big data analytics, moving up on the maturity curve are the applications that are not only proactive but also predictive [1]. For industrial companies, predictive actions can generate savings over scheduled repairs, reducing overall maintenance costs and breakdowns [2]. Industrial applications with reliable predictive features are becoming increasingly important. Predictive online simulation systems (POSS) are one particular example of predictive industrial applications with great potential. Currently, there are different model-based prediction methods to support maintenance decisions. For example, a combination of model predictive control (MPC) and real-time optimizers (RTO) is often used to plan optimal plant operation conditions for industrial process plants. However, MPC can only provide information about the process stability on a minute-level scale. Moreover, RTOs calculate the optimum operation point based on steady state process simulators [3]. The prediction function of POSS fills the gap left by other tools used for the management of production in terms of dynamic and nonlinear issues.

Summary

As part of Project 3 of the S-STEP program, we developed a tracking simulator-based POSS for the process industry (Fig. 1). A tracking simulator is a simulation model that is run in parallel with a physical process controlled by the process control system. At the same time, an update mechanism is used to keep the simulated state as close as possible to the real process, by continuously adjusting the parameters of the model after comparing the outputs of the process and the simulation. A tracking simulator can be sped up to provide predictions based on the current state of the plant, which are obtained from an adjusted model that is permanently calibrated. The forecasting capabilities of these systems are a powerful tool for the management of optimal plant operations, especially in the process and power generation industries, where planning flexible production is critical, due to the ever-changing market demands [3].

The POSS was implemented on the dynamic simulation tool Apros [4], developed by VTT and Fortum, which are partners in this project. The tracking simulator is the main component of the architecture. However, there are two other simulators designed to improve the performance and results of the system: the parallel and the predictive simulators. In the parallel simulator, a model optimization is performed so that the model results match closely the process ones before tracking is started. In the predictive simulator, a snapshot of the tracking simulator model is run faster than real time in order to obtain predictions. The system includes a historian, which is used to store data series from the physical and simulation systems. OPC UA [5] is used as the communication mechanism between all the components, guaranteeing easy and non-invasive integration of the system even during the production phase of the plant life-cycle [6].

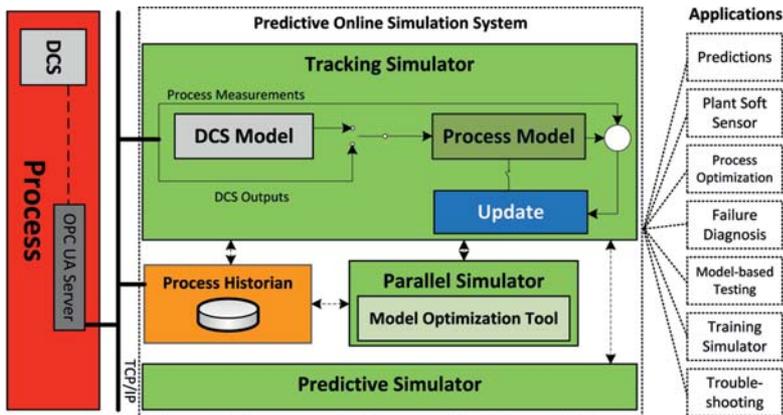


Figure 1. Tracking simulator-based Predictive Online Simulation System Architecture

Before predictions can be obtained by the system, the POSS goes through a preparation phase in which, first, the tracking simulation is initialized by running it to the current process state [7]. Then, the Parallel Simulator performs an offline multi-parameter optimization of the model. The optimization method operates by repeatedly running the simulation model with varying parameters and comparing the resulting time series with the physical process output. The method generates promising new parameter set candidates by observing the changes in the results until it selects the set of parameters that most closely matches the plant behavior. After the model optimization is completed, the Parallel Simulator feeds the optimized set of parameters into the other Tracking Simulators. Finally, the Predictive Simulator runs a snapshot of the Tracking Simulator model to calculate predictions.

Results

A laboratory-scale continuous process was used to test the POSS. The process is a small but representative water-heating production plant in which the water is first heated and then pressurized before it can be consumed. The DCS of the plant is based on the IEC 61131-3 standard. A thorough description of the process can be found at [6]. The results of the Predictive Online Simulation System are shown in Figure 2. The process variable is the water level of one of the tanks, controlled by a cascade PID controller configuration. The upper trend shows that the tracking simulator is able to keep the same state as the process even during production transients. The prediction results show the current time and the forecasted production trend. A comparison between the simulation prediction and the actual process output is presented, to demonstrate the accuracy of the prediction results.

The developed POSS is a reliable industrial predictive application, as its results are based on a simulation model that is first optimized and then continuously adjusted to match the real plant. However, it is more than just a predictive tool. Once the system is running in parallel with the process, the simulation model becomes a soft sensor of the plant, which provides non-measured data from the process [8]. The information available from the system can be used to optimize the process operation, to plan maintenance actions, or to diagnose failures. The adjusted model can also be used for model-based testing of the control application [9], as a training simulator, or for plant troubleshooting. Our Predictive Online Simulation System is a holistic solution that aims to address the need for simulation-based methods required for precise operation and maintenance planning of modern process industries.

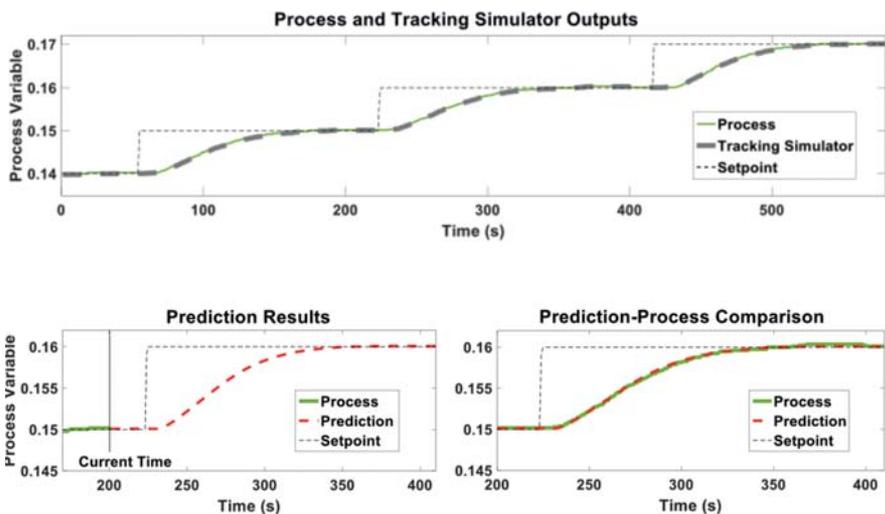


Figure 2. Predictive Online Simulation System results

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Cloud manufacturing

Background

In the current internationalization and globalization of business, market demands are volatile due to unpredictable customer demands, a diversified product range, and shorter product life-cycles (Francisco, Azevedo and Almeida, 2012). To accommodate this dynamic business environment, organizations need to make continuous changes in all aspects. In recent years, information and communication technologies (ICTs) have been fast developed and widely applied. New ICTs appear to help organizations to face the considerable challenges. Future scenarios in the manufacturing industry place technology-enabled innovation at the core of development to heighten product quality, and to reduce problems and other obstacles.

By observing the current status in the manufacturing industry, many manufacturing companies have changed their business model from highly centralized vertical operations to horizontally integrated operations. The companies did not produce everything locally, but needed to work in tandem globally with other companies, such as suppliers, partners, and customers (Gould, 2014). However, the current manufacturing solutions have not made the transition to support distributed operations (Ford et al., 2012).

Cloud computing is one of the top ten technology trends based on Gartner's prediction in 2015. Although it is not, per se, an invented concept, it has been regarded as one of the major technical enablers and new business strategies for the manufacturing industry (Tien, 2011; Xu, 2012). Cloud computing adoption can cause a paradigm shift in both information technology (IT) infrastructure and business infrastructure, particularly in IT efficiency and business agility. According to an estimate by the research company IDC (International Data Corporation), the 'cloud' will improve the productivity of manufacturers over the next decade (Adiseshan, ND). By 2020, 80% of global IT spending will be allocated to cloud computing and big data analytics (Cattaneo, 2012). Cloud computing is an ideal model for the delivery of collaborative solutions. Therefore, it is widely utilized in today's industry and society.

Cloud manufacturing is proposed for the whole product realization life-cycle, from pre-manufacturing, to manufacturing, and to post-manufacturing. It is mostly concentrated on providing all manufacturing resources as services based on customers' requirements, and its objectives are 'integrating distributed resources' and 'distributing integrated resources'. In cloud manufacturing, the definition of services is extended to a broader scope. The manufacturing services are not limited to the conventional end-user-oriented domain, but cover all phases of the manufacturing life-cycles, from design to simulation, production, testing, maintenance, after-sales services, logistics, and integration. Each organization or individual in this cloud manufacturing environment is autonomous, but they are aggregated together based on their needs from cloud manufacturing. However, cloud manufacturing makes it possible for different manufacturers to share their best practices and their unique or spare manufacturing resources/capacities in an industry-specific resource pool.

Toward a framework

Cloud manufacturing is considered as 'a system of collaborations'. The general idea is to provide a cooperative work environment in the entire manufacturing ecosystem at different levels, from field, to management, and to corporate level. This model enables both internal and external communication and collaboration across multiple companies. With the support of the cloud, manufacturing resource pools can manage geographically distributed manufacturing resources by virtualizing, collecting, and reallocating them.

Cloud manufacturing aims to break two significant constraints for multiple collaborating manufacturers: geographical distribution and temporality. It can achieve both business and manufacturing collaboration between enterprises by sharing and integrating various manufacturing resources. Cloud manufacturing offers transparent resources and supports automatic processes. It increases the level of business transparency and flexibility by dynamic configuration and portability. Cloud manufacturing can be designed for collaboration and can be used to facilitate communication. This collaboration can be discussed from two aspects: vertical information integration (i.e. intra-communication) and horizontal information sharing (i.e. inter-communication).

According to a survey of cloud-based collaboration by Current Analysis, only 11% of manufacturers used cloud services and implemented cloud-based collaboration in various formations (Current Analysis, 2014). At present, cloud manufacturing implementation is still in its initial stage. Many companies are still facing obstacles concerning understanding cloud manufacturing and how to transform their business model toward cloud manufacturing.

Figure 1 shows the scope of cloud manufacturing and demonstrates the collaboration-focused manufacturing strategy. It enables different factories and organizations to pool and provision their resources/capabilities, and to respond to a particular business opportunity; not only building a bridge between factories, but also setting up communication and real collaboration. The 'Internet of everything' concept brings together machines, users, manufacturing services, business, and all the required data and relevant information, and it also makes all the elements in cloud manufacturing more valuable and more connected than ever before.

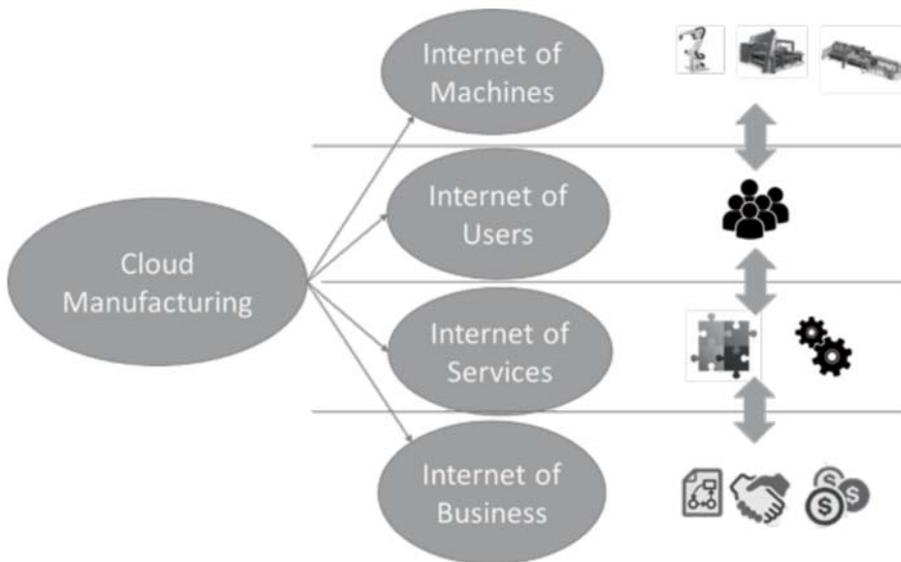


Figure 1. The spectrum of cloud manufacturing

Cloud manufacturing aims to provide high production efficiency and low energy consumption for manufacturers, and also to take full advantage of manufacturing resources (Li et al., 2010; Jiang et al., 2013). The goal of this project has been to implement cloud manufacturing-based optimization solutions in sheet-metal processing industries, and to provide professional and effective support to develop toward digitalization and embrace cloud computing.

Further information

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Company impact

“Process industry faces a strong need to reduce operating costs and environmental footprint. Level of automation in the plants is growing and new technological solutions emerge. The use of first principle models in parallel with the real process is really promising approach to be used in advisory systems. For Outotec and its customers this means capability to run the plants closer to optimal operation point, to better troubleshoot plants remotely and to detect abnormal situations more easily. S-STEP program has helped us to develop our offering to this direction.”

*Jussi Järvinen, Director – Process Control and Monitoring Platform
Outotec*

KNOWLEDGE-SHARING SOLUTIONS FOR FIELD SERVICE PERSONNEL

Eija Kaasinen, Susanna Aromaa/VTT
Jouni Törnqvist/Bronto Skylift

Project motivation and achievements

The industrial internet and service business have potential for radical improvements in field services regarding service quality, work satisfaction, productivity, and risk reduction. In the DIMECC S-STEP program, we have developed augmented reality-based concepts of knowledge-sharing solutions for mobile service technicians. The user evaluations of the solutions have shown that fluent access to situationally relevant data in situationally relevant mode and automatic or effortless reporting have the potential to increase both productivity and work satisfaction.

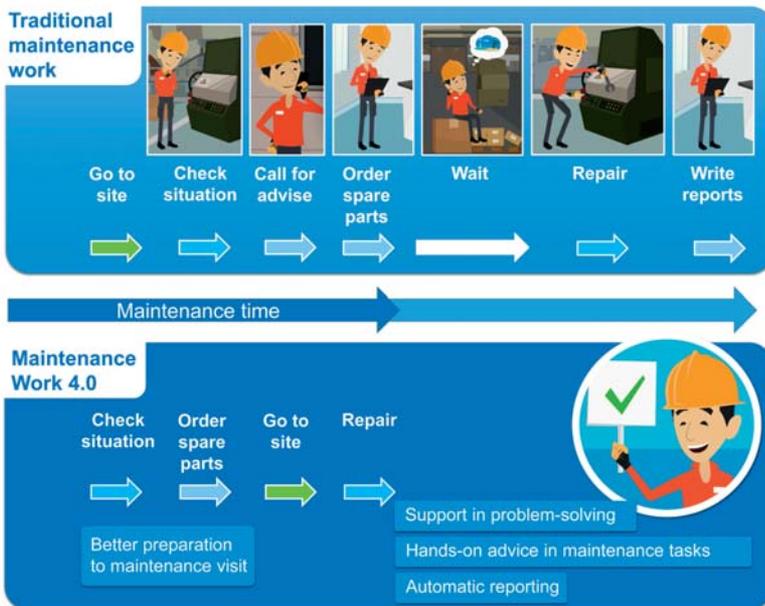


Figure 1. Mobile service technician 4.0 is much more efficient than a traditional service technician, due to the industrial Internet and IoT, which facilitate easy access to situationally relevant data

The industrial Internet and IoT do not only mean digitization, that is, producing data and making it available. An important part of the development is utilizing the data in different work activities. The industrial internet and novel interaction technologies can dramatically affect the work of service technicians in the field. At the moment, service technicians may spend only a few hours each day on value-added work, while most of the time is used on waiting, searching for information, and reporting (Figure 1). The data needed in maintenance work can be existing documentation, measured data, or information produced by peers. All this data can be made available to maintenance persons with augmented reality (AR) solutions, so that situationally relevant knowledge with appropriate modalities supports their work. Successful solutions are based on a thorough understanding of the maintenance work and its knowledge-sharing information needs.

Recent advances in both hardware quality and pricing enable the adoption of powerful AR and multimodal technologies on lightweight yet powerful mobile and wearable devices. In addition, the related 3D tracking technologies, sensors, and depth cameras enable implementation of multimodal AR even in challenging industrial environments. Figure 1 illustrates the foreseen changes and benefits of the knowledge-sharing solutions. The technician will be able to proactively identify defects and order spare parts before arriving at a site by remotely reviewing, for example, real-time data on machine performance. Moreover, the technician will have easy access to contextual information about the site, such as upgrades to the maintenance target or information about the complex environment in which the maintenance target is located. This makes it possible for the service technician to be better prepared for the maintenance visit. Once on-site, the technician will be assisted in making repairs by augmented-reality and virtual-reality technology-based instructions, and can receive remote guidance from experts off-site. The reporting and the gathering of the tacit knowledge will be done automatically during the maintenance work.

Figure 2 illustrates an example by Bronto Skylift of the information and data flows related to maintenance work. Firstly, there is a lot of prepared material, such as manuals and instructions. Different multimedia material gathered from previous maintenance visits can be made available, such as photos, 360° video, and sound. During the service operation, the technician can record more of this kind of material for the benefit of upcoming maintenance visits. Relevant multimedia material of the maintenance operation can also be stored automatically. Failure codes can be automatically linked to those materials to support finding relevant materials from the field reports. The machines are more and more

capable of monitoring their own parameters, and this can be a kind of black box, always available for diagnostics. A best practices database stores descriptions of previous successful solutions to problems. Social media-based, context-aware knowledge-sharing solutions that have been developed in S-STEP provide good complementary content to those. Finally, an online connection to a spare-part database helps in finding relevant spare parts and related instructions. The information gathered during maintenance visits is analyzed and the information sources are updated accordingly.

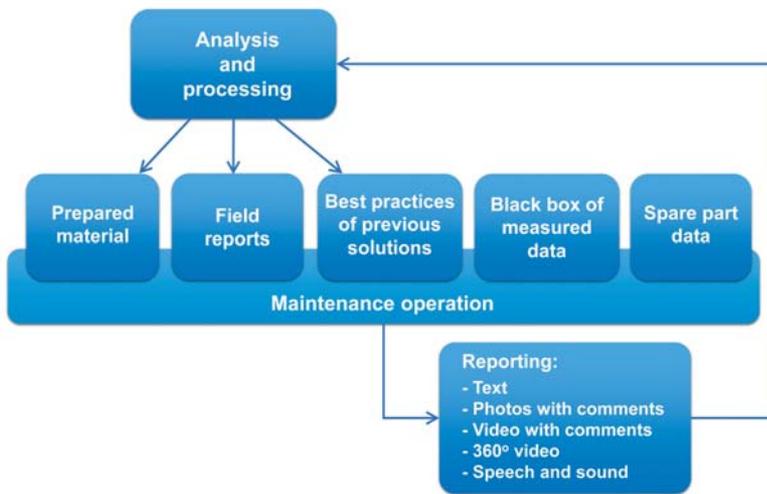


Figure 2. Information and data flow during the maintenance work at Bronto Skylift

The foreseen change in maintenance work will generate benefits for maintenance workers, service provider companies, and customers. Most benefits to maintenance workers derive from the availability of information and automated secondary tasks. Therefore, the maintenance persons can work more fluently, and they can be confident in getting support when needed. The main benefits for the service provider company are faster and more efficient maintenance, as well as better service quality. The service provider company will also benefit from the ownership of the all the knowledge that is related to the maintenance. Customers will gain most benefits from fast, efficient, and predictable maintenance.

The new solutions will significantly improve the productivity and enjoyment of work for service technicians in the field. The comic strip on the following pages illustrates our vision of a future mobile service technician's work. We identified five thematic areas (Figure 3) where mobile service technicians will benefit from S-STEP solutions: 1) being

better prepared for the maintenance visit, 2) getting contextual guidance during the fault detection and maintenance operation, 3) receiving fluent support for data gathering and reporting, 4) getting hands-on support from remote experts, and 5) giving and getting contextually relevant peer support using social media. Each of these aspects is described in a separate sub-section with descriptions of the technical solutions and lessons learned from user evaluations. In between the thematic sections, we describe the five company showcases that were implemented in S-STEP, as well as lessons learned from them.

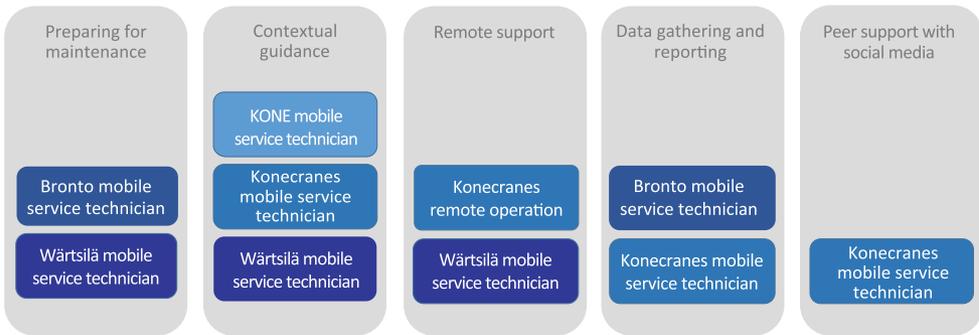


Figure 3. The five thematic areas and connected industrial cases

In addition to developing solutions for mobile service technicians, we touched the theme of integrating different information sources. Semantics based information modelling techniques were developed to describe the information and for reasoning of the relevancy of the information in different contexts. These knowledge management solutions are described in the last sub section together with 3D Studio showcase, which highlights the challenges of real time connection to current information in product life cycle management (PLM) systems.

Our future vision is that all required information will be available for the maintenance worker at any time, reporting is made automatic, and the work will be more technology-mediated and knowledge intensive. The results from DIMECC S-STEP program show that there are still lots of research challenges in providing situationally relevant data to the mobile maintenance person in situationally relevant mode. In addition, there are challenges in creating the data, so that it is cost-efficient and so that the same data can be used for different purposes, such as manufacturing, sales, and maintenance. These challenges will be the focus in our future research activities.

MOBILE SERVICE TECHNICIAN

"A DAILY WALKTHROUGH"

ON A NORMAL WORKING DAY...

MOBILE SERVICE TECHNICIAN
A daily walkthrough

LAURI HEADS TO A CLIENT SITE

SITE A
This way

Tasks

- * Go to site
- * Inspect machine
- * Inform client
- * Perform maintenance
- * Prepare reports

HE COMES ACROSS A DIFFICULT SITUATION

...never seen this issue before

I will need new spares

How long is this going to take?

SPARES ARE ORDERED...

- * Order placed ✓

AFTER A LONG WAIT...

...THE SPARES ARRIVE!

the spares arrive.

HE DEPENDS ON THE MANUAL...

to perform maintenance.

hope this works!

..TO PERFORM MAINTENANCE.

TO MAKE THINGS WORSE..

...there is lots of reporting

LET'S REDESIGN

INTRODUCING...

MOBILE SERVICE TECHNICIAN 4.0
A daily walkthrough

MY WISHLIST

- Being better prepared for maintenance visit.
- Support in troubleshooting.
- Hands-on guidance in maintenance works.
- Less reporting

Using **FIMECC S-STEP** solutions, we fulfill these wishes.

LAURI CAN NOW ACCESS THE MAINTENANCE SITE REMOTELY.

...AND BE BETTER PREPARED FOR THE VISIT

EASY ACCESS TO MACHINE DATA ON SITE

NO NEED TO CLIMB TO THE MACHINE ROOM

TRUCONNECT Alerts

SUPPORT IN TROUBLESHOOTING

BY GETTING INTERPRETATIONS OF ERROR CODES

HE ALSO GETS HANDS-ON GUIDANCE DURING MAINTENANCE TASKS...

...AUGMENTED BY VIDEO INSTRUCTIONS ON SITE

ASSISTANCE OF A REMOTE EXPERT...

AUGMENTED BY HANDS-ON GUIDANCE ON THE MAINTENANCE TARGET

ONLINE REPORTING & SHARING WITH WEARABLES

BY AUTOMATED LOG OF MAINTENANCE EVENTS, PHOTOS AND VIDEOS WITH AUDIO COMMENTS

Huge savings in time and resources with situationally relevant knowledge easily available to service technicians

...THE END!

Ville Mäkelä, Pekka Kallioniemi, Santeri Saarinen, Tuuli Keskinen, Markku Turunen
TAUCHI, University of Tampere

Preparing for maintenance

Introduction

Much industrial maintenance work is conducted in the field, where tools and information may not be readily available. Moreover, especially with large, complicated machines such as skylifts or cranes, maintenance procedures may be very complicated. Therefore, technicians could benefit from being able to remotely observe the machine in need of maintenance, as well as the area around it. In this way, technicians could prepare for the upcoming maintenance tasks with, for example, sufficient tools, and proper training and documentation.

Traditional documentation is largely static, difficult to keep up-to-date, and occasionally difficult to interpret. We argue that in many ways it would be more beneficial to see the maintenance procedure being conducted than to read about it in a document. One notable reason for this is that experienced technicians have often amassed a large pool of tacit knowledge, such as tricks that help during maintenance that may not be part of the official documentation. Current research has shown that sharing tacit knowledge can improve maintenance efficiency, and that a computer-integrated maintenance system can play a role in this (Refaiy & Labib, 2009). As such, being able to view the procedure conducted by an expert could help in passing this tacit knowledge to others. In addition, the maintenance of large and complicated machines sometimes requires them to be manipulated in multiple locations at the same time, which is often difficult to present in traditional documentation.

Therefore, we identified the need for improved ways of recording and viewing maintenance procedures. In our vision, improved documentation of the maintenance procedures could help less experienced technicians, as well as those working with the machine, to deal with the required maintenance procedures.

To further investigate improved ways of recording and viewing maintenance procedures, we looked into omnidirectional videos and virtual reality (VR). Omnidirectional videos cover the full scene (see Figure 1) and as such, enable the viewer to potentially see “everything”

around them. Furthermore, viewing such videos with a VR headset enables the user to view omnidirectional videos naturally, as the viewport moves based on the user's head orientation. A lot of scientific research has been done to enable the use of omnidirectional video in different contexts. Some of this includes remote operation and telepresence applications (Boult, 1998 & de la Torre et al. 2005). In the field of human-computer interaction, augmenting omnidirectional video with interactive content (Berning et al. 2013) and UI elements (Ramalho & Chambel, 2013) is a crucial feature in many applications.



Figure 1. Screen capture from omnidirectional video of the Bronto skylift maintenance hall. Users can freely observe the skylift and its location using a head-mounted virtual reality solution

Techniques **Amaze360**

To view and interact with omnidirectional videos, we developed *Amaze360*, a head-mounted virtual reality application (Figure 2) that enables the user to freely observe omnidirectional videos by simply turning their head, as if observing the real world. The screen is divided into two separate viewports - one for each eye - in order to create a stereoscopic effect, thus creating a sense of depth (Figure 2, right). The video content used by the application has a 360-degree horizontal and 180-degree vertical field of view, and the video is projected onto a virtual sphere. The viewport's field of view is 60 degrees.

Omnidirectional videos inside the application can be filled with interactive interface elements called hotspots. Hotspots are triggered by a technique called dwelling, wherein the user simply focuses on an element in the center of the view (by turning their head toward it) and keeps the viewport still for a short period of time (dwell time). The selection can be canceled by simply turning away from the hotspot before the dwell time has passed. Triggering a hotspot launches an action specific to that hotspot.

Currently, Amaze360 supports two types of hotspots: information hotspots and exit hotspots. Information hotspots display additional textual information about an object in the scene (Figure 2, right). The displayed text box, once shown, can be closed by turning the viewport away from it. Exit hotspots can be used to switch between videos, allowing for a multitude of different scenarios, such as observing the maintenance target from different sides.



Figure 2. Left: Amaze360 physical setup. Right: Amaze360 application view. The viewport is divided into two for a stereoscopic effect. An activated hotspot is shown at the center of the screen

In addition, Amaze360 has support to utilize 3D models (Figure 3), which can depict a certain location (e.g., a power plant) or a device (e.g., a crane). Omnidirectional videos spheres can be embedded within these 3D models, and users can then navigate between these spheres as if actually moving around the location.

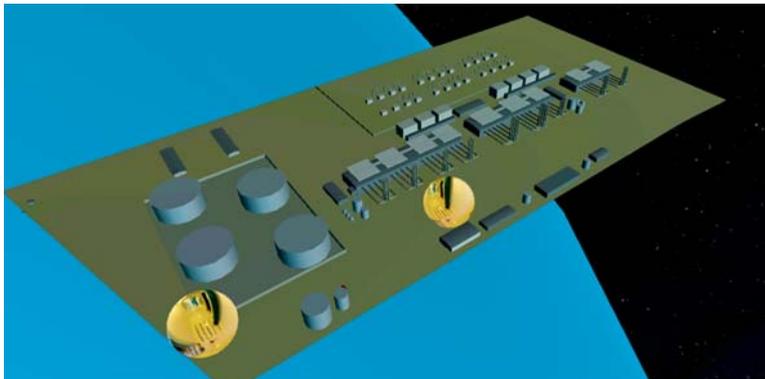


Figure 3. 3D model of the Wärtsilä power plant in the Amaze360 application

Benefits of a virtual reality solution

By utilizing the Amaze360 software described above, maintenance actions can be assisted in several ways. Firstly, we can offer the technician an up-to-date view of the location through omnidirectional videos and embedded content. This is important, as companies often maintain their installations and devices at the customer's locations, which could contain any number of other devices for which the technician could not prepare. With Amaze360, they can accurately see the actual location in its current order and prepare accordingly if, for example, the device to be maintained is placed in such a way that other devices block access to certain parts of it.

Secondly, our solution offers real-time access to machine data, which logically integrates with the aforementioned view of the location. Machine data would help in determining the issue before arriving on-site, or, by combining both machine data and information about the surroundings, issues could be resolved remotely.

Thirdly, we note the challenges with traditional documentation described in the introduction. With Amaze360, technicians can view a maintenance procedure from a new and much more dynamic perspective. One of our aims with this approach is that, with omnidirectional videos and embedded information hotspots, viewers will be able to absorb the tacit knowledge from the technician(s) seen in the videos.

Finally, with Amaze360, companies can perform training sessions remotely, but still have trainees access the sites virtually. This enables them to concentrate the training in certain locations without the need to visit the actual locations where people would be deployed during training. This is especially useful for locations that would require a lot of safety training, or for locations that are not accessible. For instance, in a power plant, some parts of the plant would need to be shut down before safe access is possible. Thus, it would save a lot of money and time for the companies to be able to visit these locations virtually, by utilizing omnidirectional videos.

Lessons learned One of our early findings is that omnidirectional video alone cannot capture everything that is relevant to the procedure. Machines being serviced contain a number of small parts, corners, nooks, and holes that the camera is unable to record, especially while the technician is manipulating them. Therefore, the concept of embedded information in the form of hotspots, as presented above, becomes a vital part of our application. Using hotspots, additional information in the form of, for example, text, images, and videos can be utilized to communicate "missing" information to the user.

Inserting this embedded data in the omnidirectional videos is time-consuming, as currently no simple tools for the purpose are available. Hence, for a large-scale use of the solutions presented here, an easy-to-use editor for placing contextual information is needed. This would also enable personnel who have no previous experience with virtual reality solutions to be able to start using the presented tools quickly with minimal assistance.

Additionally, we conducted a study in spring 2016, comparing our head-mounted VR solution, Amaze360, to a more traditional CAVE system (often used in industrial settings). Our early results show that omnidirectional videos, in general, are a very immersive medium for VR applications. Overall, the HMD application was considered to be more immersive than the CAVE system. This effect was observed with both indoor and outdoor video content. We primarily attribute the immersiveness of the HMD application to: a) the head-mount, which effectively blocks outside visual stimuli and enables concentration on the content, and b) the stereoscopic view creating a sense of depth.

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CASE WÄRTSILÄ: AR guidance, remote support, and preparing for a maintenance visit

Background and objectives

Wärtsilä is a leading service provider in the marine and energy sector, with more than 11,000 service employees working globally in more than 70 countries. One of the Wärtsilä's core competencies is a strong technical know-how that has been gathered and developed over decades. Unfortunately, some of the information is lost at an individual level, and sharing it is not as efficient as it could be. In addition, finding the required information can be demanding and time-consuming for field service engineers. Above all, preparation for upcoming maintenance work could be enhanced.

In the DIMECC S-STEP program, Wärtsilä's objective was to develop methods that provide situationally relevant information for field service engineers with the help of augmented reality technologies. In addition, the aim was to support field service engineers in preparing for upcoming maintenance work.

Results The way of working in the DIMECC S-STEP program is based on agile development methods that enable fast prototyping and validation with users. The project is divided into three different concept development streams: augmented reality guidance for field service personnel, remote guidance, and 360-degree visualization of the installation. End results from all three streams are functional prototypes that have been validated with end-users.

Impact The results of the S-STEP program have shown the real value that augmented and virtual reality technologies can bring to Wärtsilä's business. Prototypes have worked as eye-openers in understanding what the possibilities really are and how they can be achieved. Most importantly, S-STEP has highlighted the real value for the users, which is a key driver for future development.

Augmented reality guidance

In this concept, the maintenance technician receives help that is available in information systems via a tablet PC and an AR application. The concept is targeted at planned and preventive maintenance services, where the technician goes through a predefined set of tasks. The maintenance technician will be given a list of maintenance steps and visual guidance on what to do in the following steps. The system enables the maintenance



Company impact

"Already from the early S-STEP results we have circulated internally in our company it has become clear that contextual guidance, remote support and 360 degree VR visualisations have a high potential of impacting the way we educate, prepare and perform maintenance tasks. Excitement has been high, and concrete cases for piloting these technologies are being actively considered."

*Mikael Leppä, Lead User Experience Designer
Wärtsilä*

technicians to proceed at their own pace, and acknowledges when a maintenance step is completed. The system therefore ensures that all necessary maintenance procedures are performed, and enables the information to be updated in the customer's system. No other technical support personnel are needed.

Remote support

Here, the field service engineer gets real-time guidance on a tablet from a remote expert operating on a PC (voice communication and visual elements). The difference from normal conference calls (i.e. Skype) is that visual elements that are placed in the user's view on the tablet remain in place. This enables the field service engineer to put the tablet down while working. After the job is done, when the tablet is raised back into position, the markings have remained in place. This eases the workflow and enhances communication during remote support, where speed and accuracy of service are critical.

Preparing for a maintenance visit

A good understanding of the customer's installation and assets is a key starting point for efficient and high-quality service. 360-degree visualization from the installation enables the field service engineer to make a virtual tour of the customer's installation, and to get familiar with it before arrival. In this way, the field service engineer can efficiently start the work right after arrival. During the S-STEP program, two installations were filmed (a power plant and a vessel) with six GoPro cameras. The video material was stitched together using Kolor software and run in the Unity game engine, enabling movement. Information can be viewed using VR glasses, a tablet, a phone, or a laptop.

Lessons learned

The augmented reality guidance concept was validated with field service engineers, and it was found to be a useful tool even for the more experienced engineers. The technology that was used in two of the concepts is no longer available, due to changes in the industry. A major challenge in the future will be how to create AR content efficiently. The idea of the remote support concept was also valid, but fluent use of the application requires more UI design. First impressions from the 360-degree visualization concept have been very promising, but it still requires more end-user testing to validate its added value. The main conclusion from the results is that all the three concepts: contextual guidance, remote support and 360 degree visualizations are very promising, and they are definitely a step toward the future of the maintenance business, which may be closer than we think.

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Contextual guidance

Introduction

In the global service industry, access to versatile and situationally relevant knowledge is increasingly important for service quality and productivity. At the same time, knowledge is becoming less accessible on a person-to-person level, due to multi-vendor global services and employee turnover. Figure 1 illustrates typical knowledge needs in field maintenance. The knowledge needs vary on different service sites, in different service operations, and with individual service technicians. Figure 2 illustrates knowledge sharing paths where explicit information can transform into tacit knowledge and vice versa.

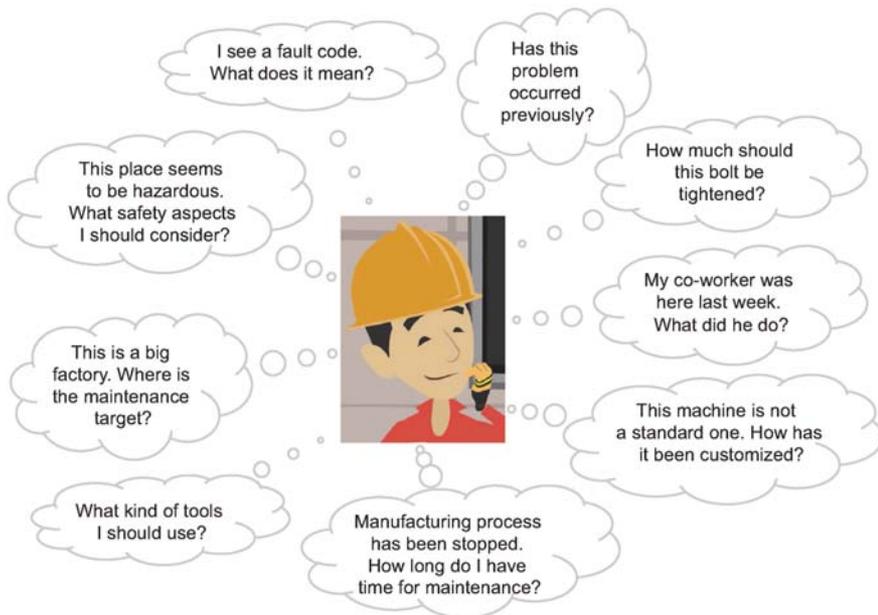


Figure 1. Illustration of needs for contextual information during maintenance

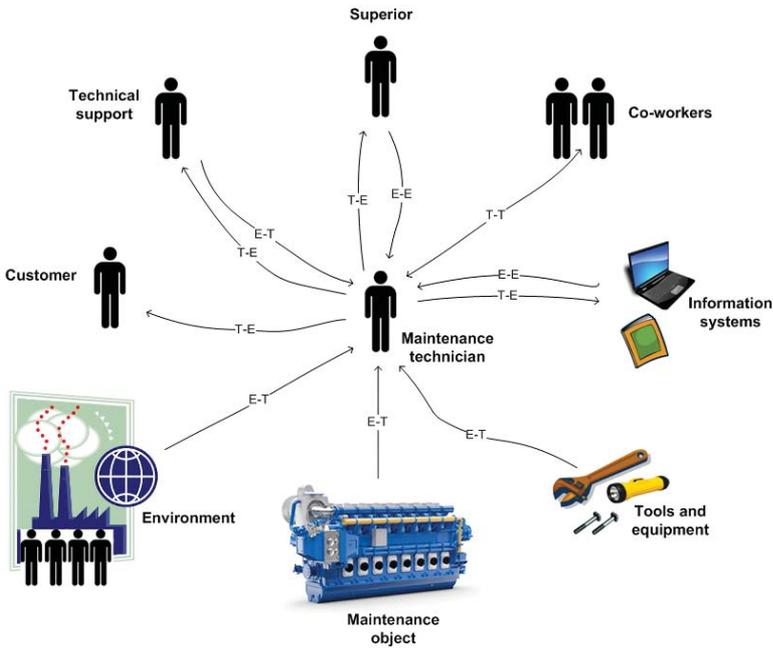


Figure 2. Knowledge sharing paths in maintenance work (Aromaa et al., 2015).
E = explicit knowledge, T = tacit knowledge

Previous research (e.g. Baird & Barfield, 1999; Day et al., 2005; Kunze, Wagner & Kartal, 2009; Henderson and Feiner, 2009 & 2011; Tang et al., 2003) suggests that AR technologies are promising in providing instructions because they are often faster to use and errors occur less frequently than with traditional paper instructions. Operators also seem to approve of the technology. Solutions based on augmented reality (AR) and wearable technologies were developed and used in the S-STEP program to study how the solutions support maintenance work, and how maintenance technicians feel about the solutions.

Augmented reality-based guidance during maintenance tasks

Contextual guidance was studied in the S-STEP program in Wärtsilä, Konecranes, and KONE cases. With AR maintenance, technicians can get interactive, comprehensive, and situationally relevant guidance.

Maintenance technicians can get *step-by-step augmented reality guidance* during maintenance operations. This was studied in the Wärtsilä case (showcase implemented by 3D Studio Blomberg Ltd.), where the purpose was to give comprehensive and interactive guidance to the maintenance technician (Aromaa et al., 2016). The system is based on

planar image tracking, and that is why no special markers are needed. Instead, 3D markerless tracking is used in the form of 3D point cloud recognition. Visual guidance is provided and stitched to the 3D point cloud, correctly oriented on the physical product in the form of 2D drawings, 3D models, or symbols (Figure 3). The correctly oriented point cloud tracked by the software on the mobile device allows for information to appear in physically relevant locations. Animated guidance enables a demonstration of how to carry out maintenance operations. Step-by-step contextual guidance enables maintenance technicians to proceed at their own pace, acknowledging when each maintenance step is completed. The system ensures that all necessary maintenance procedures are performed, and maintains a log of the operations in the customer's system.

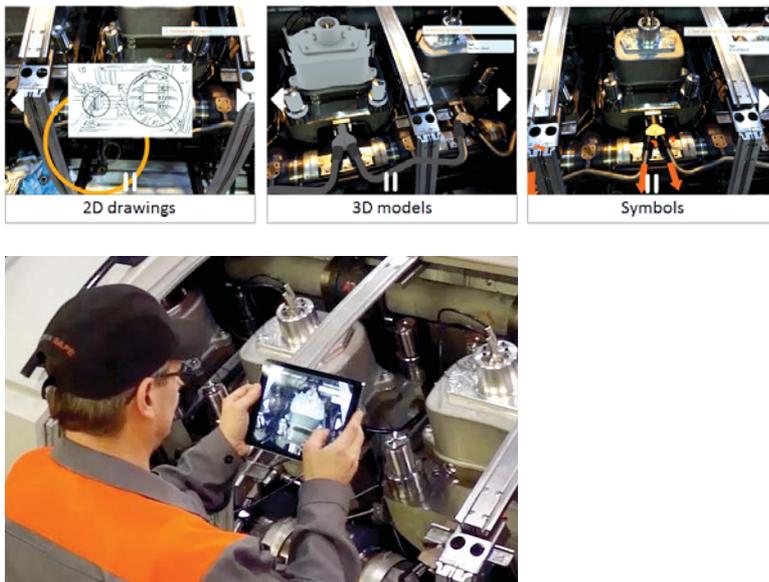


Figure 3. Step-by-step guidance in the Wärtsilä case

Augmented reality can be used to provide *real-time data related to a component*, such as its usage data and fault codes. This was studied in the Konecranes case, where a smartphone was used to provide the real-time contextual information (Figure 4) with the help of AR and social media features. The augmented reality application used both marker-based tracking (upper-left image) and planar image-based tracking (upper-right image).

The maintenance technicians were able to get contextual information about components (e.g., condition, lifetime, alerts, and fault codes). The system tracked items inside a box and the technicians were able to

receive more information about the marked objects. The technicians can also take photos of the components, point to specific parts on pictures, and add notes. This user-added contextual and component-related information is shared using social media features, and other users can browse or search these remarks.

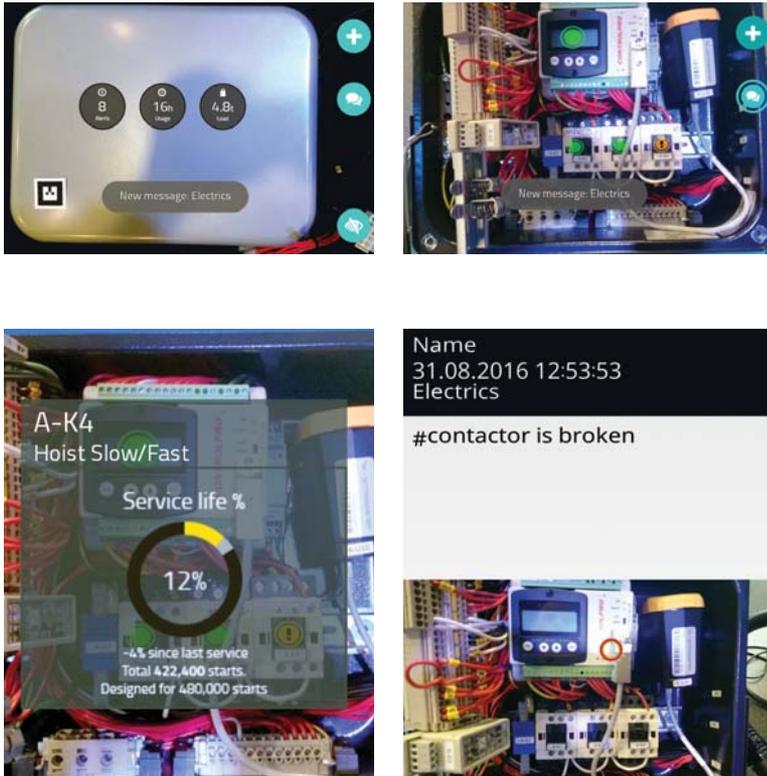


Figure 4. The Konecranes case augmented reality and social media solution
© Konecranes

Error codes in machines are often indicated by LEDs or numeric codes. The mobile service technician can be supported by interpreting these codes and giving related maintenance guidance. This approach was studied in the KONE case, where the service technician typically started analyzing the situation from the elevator maintenance panel. The maintenance panel presents error codes in a 7-segment display, and depending on the code, the service technician needs to check several LEDs to pinpoint the potential error source.

For testing, we implemented a mobile phone application to recognize and track, in 3D, one specific maintenance panel (Figure 5). In addition, the application automatically recognizes the error code from the 7-

segment display, and it records which LEDs are on. With this information, we made a simple decision tree for a few test cases that are relatively easy to test on the physical elevator. Based on the decision tree, the application can give the service technician guidelines based on the error code and the LEDs.



Figure 5. In the KONE case, the software recognizes a 7-segment display and LEDs on the elevator maintenance panel. It can use this information to automatically recognize error codes and to give guidelines to the maintenance worker

Location tracking and contextual guidance with augmented reality

Location tracking has several different helpful purposes in the work of the maintenance worker. First, it can be used to guide the worker on a site where they have never worked before. In this way, the worker can independently travel to the required location for the task. Second, tracking can be used to ensure that the worker is actually doing the work in the correct location on the correct machine. In this case, a supervisor can also see that the worker has actually been in that location. Most importantly, location tracking can be a safety tool for the worker. It can prevent them from entering dangerous areas. Supervisors can also determine if there are any workers in unsafe areas during alarms.

In the S-STEP program, two different methods were tested for implementing location tracking. In the first case, printed ID tags were used, using the MetalIO platform to pinpoint the location of the user. Locations and rotations of these ID tags were defined on the map. Using this predefined information, the platform could locate the middle point of the image and its direction, and using trigonometry it could calculate the angle of view with reference to the AR-enabled device running the software. When the user sees one of the previously mentioned ID tags, an arrow pops up on top of that tag, and it points in the direction of the location that user has chosen before.



Figure 6. Location tracking with AR guidance using MetalIO platform

In the second case, the Google Tango platform was used. This platform has an in-built location-tracking feature that uses inertial measurements working in combination with Tango's area learning capabilities. This case demonstrated the possibility to add different checkpoints, using the Tango tablet, to any area that was previously "scanned" with Tango's own area

learning tool. This checkpoint can hold any kind of information, from mechanical datasheets to measurement values. In this maintenance concept useful information could be for example work instructions illustrated with 3D animation. When the maintenance worker enters the checkpoint area with the tablet, that information pops up for the worker.



Figure 7. Location tracking combined with contextual AR guidance using Google Tango platform

Tango platform's location tracking capabilities were also briefly tested in a local paper factory in a limited small area. Despite of the harsh conditions of the area, the location tracking worked almost flawlessly. Only unlit places were problematic because the camera could not see well enough to recognize the area. In these situations Tango has to rely only on inertial tracking, which causes drift over time.

Tango's location tracking platform was also tested to track one large object, in our case a large vehicle. Only the sides of the vehicle were scanned with Tango, and surroundings were left out. In this way Tango could identify user's location relative to the vehicle in all different locations where the vehicle could be located.

Lessons learned

Our findings from the studies support the assumption that AR technologies serve well in providing contextual instructions in field maintenance work. The maintenance technicians' experience was positive toward the use of the solutions in their work. In particular, AR contextual guidance can be useful in demanding maintenance tasks that are rarely carried out, or in situations where it is not possible to ask for advice from other people. One of the advantages of AR guidance is that instructions are easier to keep updated, and can be more illustrative than paper manuals

(e.g., by projecting information on top of a real machine, and by using symbols and animations). In troubleshooting, the situation analysis can be partially automated by recognizing error codes and giving guidance accordingly. The error codes and related information can further be stored for future reference. In addition to maintenance guidance, the technician can get information about the maintenance history and previous maintenance operations.

A major challenge is how to produce AR guidance efficiently. That is why it should be carefully considered for which situations the guidance is actually needed. In the S-STEP studies, maintenance technicians commented that they know periodic maintenance tasks well, but support was needed with problem-solving. Contextual guidance solutions facilitate developing maintenance processes so that less expertise is needed in the work. The selection of appropriate media and input methods for guidance is also an issue (e.g., a tablet device or smartphone may constrain too much the free use of hands). Similarly, it is also important to thoroughly consider how the information is presented in the AR solution (e.g., symbols, text, colors, sounds) to maintain good efficiency and usability.

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CASE KONE: Mobile service technician

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Petri Honkamaa/VTT

Background

KONE is one of the global leaders in the elevator and escalator industry. The company's services cover the entire lifetime of a building, from the design phase to maintenance, repairs, and modernization solutions. The maintenance business involves more than a half of KONE's 49 000 employees and produces one third of the company's total sales. KONE's maintenance base contains more than one million elevators and escalators.

KONE aims to deliver the best people-flow experience in the industry. Safety and quality are highly prioritized in all company actions and offerings. Especially from the service business point of view, this is a great challenge due to the diversity of KONE's maintenance base, which is growing constantly due to new and technically more advanced equipment from KONE and other manufacturers. In addition, the highest increase in the global maintenance base is located in areas with a low education level. The following factors motivated KONE to study augmented reality technology (AR) in DIMECC's S-STEP program.

KONE objectives in investigating augmented reality solutions in S-STEP

- The growth of the KONE maintenance base, especially in Asia
 - The challenge to acquire a skilled workforce
- The maintenance base is technically diverse
 - Many manufacturers and equipment generations
 - Long lifetime of the serviced equipment
 - A vast amount of tacit knowledge in experienced technicians
- Productivity improvement
 - Optimizing the time on-site without sacrificing maintenance quality
 - Fixing the equipment right first time



**Company
impact**

"Augmented reality in the industrial context is not a fad. Very likely, it will be a common instrument for service technicians in the coming years. However, making the most out of it requires strong collaboration with technology vendors, but more importantly, an understanding of how the internal processes need to support the AR solution. S-STEP program has accelerated our entry to augmented reality."

Riitta Partanen-Jokela, Director, Maintenance Development, KONE

Results The DIMECC S-STEP program provided KONE with an insight into AR technology – the state-of-the-art, direction of evolution, and main players both globally and domestically. Equally valuable was the understanding of what benefits and challenges AR offers for KONE. The research was conducted in two phases. Phase 1 mainly focused on understanding the benefits and technical challenges in utilizing AR in KONE’s global maintenance process. In phase 2, a prototype mobile solution in the elevator maintenance and troubleshooting context was created.

Impacts The most profound finding of the research for KONE was the maturity of AR technology and the diversity of the offering, contrasted with the large burden of creation of content for solutions. This encouraged KONE to engage deeper into AR-related research and to discuss having the relevant content creation processes already “AR ready”.

Feasibility studies Phase 1 focused on understanding AR technology and its benefits and challenges to KONE. In addition to valuable S-STEP project meetings, KONE had one-to-one meetings with companies offering AR solutions and companies in a similar position to KONE as a technology consumer. Internal discussions were conducted inside KONE R&D to recognize all relevant parties in the AR context. A concrete AR solution prototype for a maintenance technician was defined with VTT. Solution development was started, and the first technical feasibility tests were carried out with a test elevator.

Mobile support in maintenance troubleshooting During phase 2, an AR solution prototype for an Android smartphone was developed. The solution aimed to aid the technician in troubleshooting an elevator with certain technical problems. The main goals were to provide an easier view of the elevator status on top of the rather complex maintenance user interface of the elevator, and to provide quick and concise solution descriptions for the issues recognized by the prototype tool.

The showcase focused on a situation in which the maintenance panel of an elevator has an error code presented in a 7-segment display, and depending on the code, the service technician also needs to check several LEDs to pinpoint the potential error source. A mobile phone application was developed to recognize and track, in 3D, one specific maintenance panel (Figure 1). In addition, the application automatically recognizes the error codes and records which LEDs are on.

The application idea was discussed with KONE maintenance experts. Furthermore, the prototype version was tested in an actual elevator environment. In discussions with the KONE personnel, the proposed approach was recognized to have many advantages compared to the current method of using a physical book for reference.

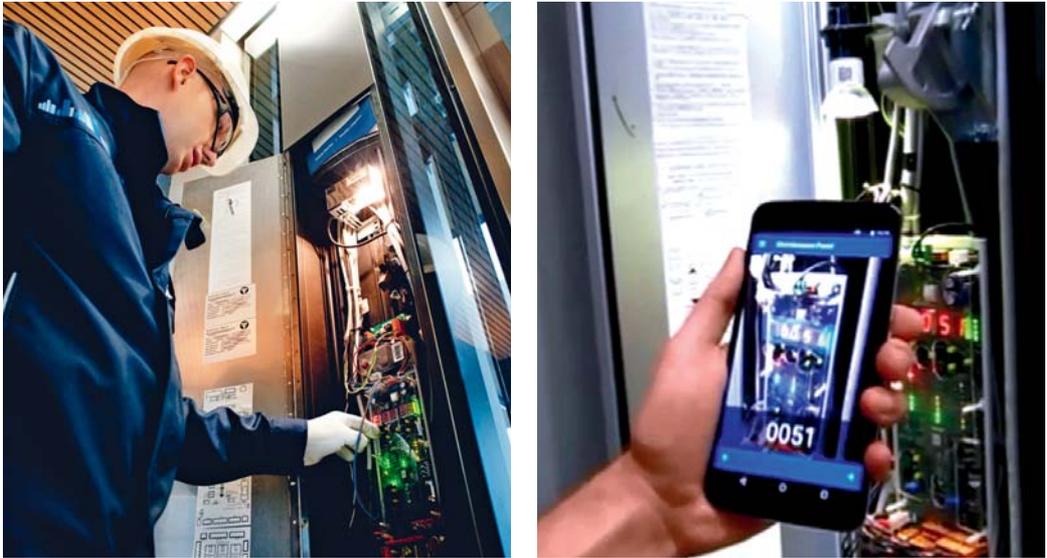


Figure 1. Maintenance panel. © KONE Corporation

- The error codes can be recognized faster and lot of the situation analysis can be automated.
- Elevators can have different codes depending on the software version. An electronic reference manual is easier to keep up to date.
- The recognized error codes and photos can be stored in a log for future reference.

Lessons learned

Augmented reality in the industrial context is not a fad. Very likely, it will be a common instrument for service technicians in the coming years. However, making the most out of it requires strong collaboration with technology vendors, but more importantly, an understanding of how the internal processes need to support the AR solution.

Augmented reality solutions not necessarily need to be technologically overwhelming nor utilize wearable technology. Standard smartphones can deliver AR solutions with proven benefits.

Remote assistance

Introduction

Even if the maintenance technician has access to various knowledge sources during the maintenance operation, there is still sometimes a need for assistance from human experts. The industrial internet, as well as new interaction tools, provides promising solutions for remote assistance. *Remote human assistance* tools can support human-to-human collaboration by giving the remote expert a hands-on experience of the maintenance target, and on the other hand giving the maintenance technician in the field an experience of the presence of the supporting expert.

Technologies for actual remote maintenance operations can be divided into two categories. Remote assisted maintenance includes devices being helpful and/or replacing the human in maintenance work. Such a device can be, for example, a remotely operated manipulator performing pre-defined maintenance tasks (LUT_mobile_assembly_robot, 2016). The second category is Remote operation, where the human operator is separated from the working machine and/or operating the machine semi-autonomously.

In the following, we describe remote human assistance, remote assisted maintenance, and remote operation, each in a separate sub section.

Remote human assistance

The purpose of a AR-based remote assistance solution is to support communication and information-sharing between a maintenance technician and a remote expert. With an AR solution, the technician and the expert can share the same view of the maintenance target, in which both can add visual elements. Voice communication supports the collaboration. In the Wärtsilä case, the maintenance technician was using a tablet PC and its camera as a medium to transfer images and video of the maintenance target. The remote expert shared visual indicators of the view on the tablet, indicating how and with which components to proceed. The remote expert used his PC to give this guidance. The given guidance can be stored so that it can later be used as maintenance support in similar situations without the presence of the expert.

Remote assisted maintenance

Devices that are helpful and/or that replace a human in maintenance work are usually capable of carrying out some simple maintenance tasks. A professional user controls the device from a remote operation desk. There is a lot of demand for remote assisted maintenance devices in the current market in machine maintenance. The work cycles get more and more hectic, there may be fewer field maintenance personnel available, and a machine's technological development may go beyond the staff's professional skills. Thus, automating maintenance (fully or partially) is a competitive alternative to training highly skilled professional maintenance staff.

Remote assisted maintenance (RAM) has been under investigation for at least a quarter of a century. With a manipulator device carrying out the maintenance tasks (LUT_mobile_assembly_robot, 2016), the tasks need to be quite simple and straightforward. For example, a task could be of a 'pick and place' type. Such frequent heavy tasks could be feasibly done by a machine. The operator can control multiple manipulators in parallel from the remote operation desk. Basically, manipulator operation and control is similar to remote operation.

Current set-ups for RAM involve more and more virtual reality (VR) and augmented reality (AR). These are to create better communications between the expert in his office and the maintenance people working at a remote site. One essential part of a RAM device is the diagnostics system for communications (Harmo et al., 1999).

Remote operation

In remote operation, it is possible to control the machine or multiple machines from a distance. The benefits of doing so are to make the operators' working environment more ergonomic, safe, and convenient. By inserting more machines in the same human-machine interface (HMI), it is also possible to save labor costs. Automated machines need interference in their operation in certain situations, but mainly they run an automated work cycle. Thus, it is economically beneficial to have centralized remote operation.

At its simplest, remote operation is, as is nowadays standard, that the operator stands beside the machine and operates the machine remotely. Remote operation offers flexibility in the operator moving around the working area, thus with better visibility and safety, and less need for manpower for the task to be completed (Cargotec, 2009). A wide variety of machines are operated remotely in this way, and even complex machines are implemented as remote-operated versions (Sandvik, 2016). Despite the benefits, it is still a harsh working environment for the operator. Therefore, there needs to be a remote operation desk located in a safe and comfortable environment, away from the working site (Konecranes, 2016).

When re-locating the remote operating station, new problems arise. The operator loses sensitivity and feeling for the work. Without hearing and feeling the working machine during action, the contact with the work is partially missing. Thus, the operator can easily overload the working machine and break it. Applying too heavy control signals can lead to premature wear in machine components.

As a solution for hands-on experience, a haptic controller is introduced. The haptic controller provides force feedback to a control joystick. This feedback indicates the forces and movements of the working machine and helps the operator to adapt the control applied to the machine. In the Konecranes case in the S-STEP program, a novel multimodal user interface to control a rubber-tired gantry crane (RTG) was studied (Konecranes, 2016). The new case was built on top of a haptic controller technology developed at the Lappeenranta University of Technology (Luostarinen et al., 2016). The prototype controller is capable of reproducing multiple modalities in all directions, load control, and possibly conceptualizing sway caused by wind. The virtual twin of RTG has been created. The haptic controller has been tested in a virtual environment. The virtual environment gives a good approximation of the Konecranes remote operating station (ROS) and the RTG in a specified work cycle.

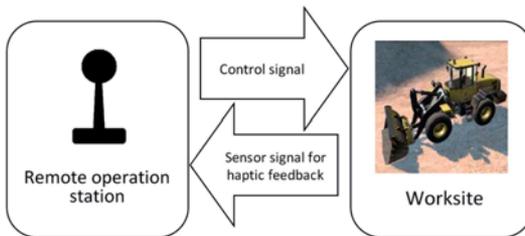


Figure 1. Remote operation communication interface (Luostarinen et al., 2016)

During the DIMECC S-STEP program at Konecranes and at Lappeenranta University of Technology, the use of a multimodal controller was studied and developed. The study of the use of a multimodal controller was carried out in two different phases. In phase 1, the study concentrated on adjusting the lifelikeness of HMI that a developed controller can provide. In phase 2, the focus was on the controller and an evaluation of the signals that it transmits to the user.

Benefits and challenges

The remote human assistance concept is promising, as it enhances communication and interaction between maintenance technicians and remote experts. The best maintenance experts can be utilized globally with the concept. The concept improves the quality and efficiency of

communication using a shared view, and it makes communication more intuitive (e.g., by introducing the possibility of pointing to objects). By storing the guidance situations, contextual guidance material can be generated. A possible challenge in this concept is that an online connection may not be available in all maintenance locations, or the connection may not be reliable. Remote assistance needs to be planned carefully so that it does not slow down or cause a distraction to the field maintenance work.

The use of remote operation with a multimodal controller interface is still in the transition phase. The experiences from the Konecranes case show that there are two schools of remote users. The first consists of former real-machine drivers. Their drawback is the slow adoption of virtual techniques, but they are superior in understanding machine dynamics and giving good control. The other school consists of novices who are educated, modern, and can easily adopt all the virtual techniques of ROS. Their main drawback is a lack of understanding of machine dynamics, and thus they can break the machines by inappropriate control. The remote haptic controller needs to have a different set-up for each school. In addition, individuals may like to have different settings. In a virtual environment, the controller can be pre-set, allowing quite free choices according to individual preferences.

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CASE KONECRANES: The use of a haptic controller in remote operation

Automation is unquestionably a megatrend in the container-handling industry, but it is not the only way to improve productivity and safety. Manned cranes are still in the majority in container terminals. By de-coupling the operator and crane, the operator can work in a safe and ergonomic office environment. The remote operator can operate different cranes at different times, which eliminates the operator's idle time. Remote operation can produce significant productivity increases and improve employee safety and satisfaction.

An operator working remotely is not in direct touch with the machine, so some of the natural human-machine touch and feel is lost. In the DIMECC S-STEP program, we had an opportunity to study the use of new technology in giving a better user experience in remote-controlled crane operation. The overall objective for Konecranes was to study whether haptic feedback could overcome the challenges that are caused by the nature of operating remotely.

Results During the DIMECC S-STEP program at Konecranes and at the Lappeenranta University of Technology (LUT), the use of a multimodal controller was studied and developed. The study was carried out in two different phases. In phase 1, the study concentrated on adjusting the lifelikeness of the human-machine interface (HMI) that the developed controller can provide. In phase 2, the focus was on the controller and an evaluation of the signals that it transmits to the user.

Impacts The research done in S-STEP has raised awareness at Konecranes. It is a known fact that engineering has lost something from "old-time haptics" by making remote-operated machines. This research has taken place to bring the sense of touch back to HMIs. The project has created a good dialog between the teams inside the organization.



Waiting for job
No. 1
ASC 001 69.1 m
ASC 02W 166.1 m
1.9 m
0.0 °
0.0 °
18.1 m
0 t
5 m/s
HONEYWELL

Remote operation

In semi-autonomous port operations, there is a need for an interface between the autonomous functions and the manual remote operation. A novel multimodal user interface to control a rubber-tired gantry crane (RTG) was studied during the program. The controller was developed outside the S-STEP program, but the usage and characteristics of the controller were studied within it. A haptic force feedback controller can create an immersive, natural, and comfortable user experience with remote-controlled machines. A prototype of an adaptive control platform and user interface has been created, and the prototype has been evaluated in a virtual environment.

As a starting point, the new case was built on top of haptic controller technology developed by Lappeenranta University of Technology. The prototype controller has been tested, and it is capable of reproducing multiple modalities in direction, load control, and approaching limits. A virtual twin of the RTG has been developed. The haptic controller has been tested in a virtual environment. The virtual environment gives a good approximation of the Konecranes remote operating station (ROS) and the RTG in specified work cycles.



Figure 1. The remote operation station (ROS)

During the first phase of the case study, an experienced test driver tested the haptic controller in a virtual environment, providing comments to help develop the interface further. In addition, the project members visited an authentic port environment in order to get a full scope of the work.

With the gained information, it can be stated that the lifelikeness of the virtual environment is sufficient, and the controller will definitely add value to the remote operator's work.

During the second phase of the case study, four teams (in total, 15 people) from the Konecranes R&D and Ports business units tested the haptic controller prototype in a virtual environment. Even though the test users were not actual operators, and each test operation was short, plenty of comments and opinions were gained to help further develop the controller interface. The gained information was qualitative and heterogeneous, and it revealed some dos and don'ts about the use of haptic feedback.

**Lessons
learned**

Haptic feedback should be optional and adjustable, since operators' experience, operating style, and preferences vary. The number of haptic signals can easily overburden the operator, so it is essential to choose the ones that are actually useful, and make them recognizable from each other. Using simultaneous visual indications will help in learning the meaning of each haptic feedback. Current feedback is limited to the information that is already tracked by the crane's control system. New meaningful feedback types could be found with richer information about the operation or the environment.

READ MORE:

http://www.konecranes.com/sites/default/files/download/automated_rtg_brochure.pdf

KNOWLEDGE-SHARING SOLUTIONS FOR FIELD SERVICE PERSONNEL

P4.4

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Data gathering and reporting

Introduction

Information is becoming increasingly electronic. However, due to the lack of proper, automated, and easy methods for data gathering and reporting, technicians are increasingly required to perform manual reporting. There is a clear need to ease the data gathering and reporting, so that technicians would be able to concentrate on their core tasks. Suitable methods would most likely increase technicians' motivation for reporting in the first place, thus resulting in better quality content as well. Although a company's core business concept may be in manufacturing, for example, supporting and developing maintenance-related tasks is also very important, as many companies nowadays provide service packages that include maintenance.

In S-STEP, we investigated techniques to improve data gathering and reporting. Here, we concentrate on wearable devices, omnidirectional content, and speech-based interaction with a maintenance support system. Wearable technologies can be used for utilizing information and reporting online and on-site. Omnidirectional pictures and videos can be used as a way of recording tacit knowledge and to monitor certain information, which in turn may be utilized in maintenance planning, guidance, and training. Speech-based interaction, especially speech recognition-based input, can be used in more traditional reporting, or in going through a step-based task list.

Wearable devices

Technologies and concepts

In the Konecranes showcase, a solution for data collection and reporting was developed in order to shorten the reporting time and improve the quality of knowledge-sharing with customers and other personnel reading the reports and remarks. Another aim was to improve the contextual awareness of the maintenance technician. The maintenance objects

included Bluetooth beacons, which were recognized automatically and which sent necessary information on the maintenance objects. Data gathering and communication between information systems and the maintenance technician are maintained using wearable devices. The concept utilizes a combination of three different wearable devices: a smartphone, a smart watch, and smart glasses (Figure 1). With the smart watch, the maintenance technician is able to select the maintained object and component from a structured interface, and choose either photo-taking or error reporting, which are directly linked to the component selected. The smart glasses are used for checking information and taking photos hands-free. The technician is able to control the smart glasses with gestures. The smartphone is used for adding text to reports and for locating a maintenance object.



Figure 1. The wearable devices concept, utilizing smart glasses, a smart watch, and a smartphone. © Konecranes

Two Konecranes maintenance technicians, one a novice and the other experienced, tested the wearable data-gathering and sharing solution at a customer site. The technicians performed a typical maintenance operation for a predefined object, and during the maintenance they used the wearable system as follows: 1) they received the task and started the task with the smartphone, 2) they browsed the target information using the smart glasses, 3) they selected the specific target using the smart

watch, 4) they took photos and reported using the devices, and 5) they checked the report using the smartphone.

Omnidirectional pictures and videos

Documenting maintenance tasks effectively and in useful ways is difficult. As described in Chapter 4.1 Preparing for maintenance, there are challenges and limitations with traditional documentation, and such documentation also usually lacks tacit knowledge. We investigated the use of omnidirectional videos and pictures in capturing maintenance procedures and the objects under maintenance. Omnidirectional videos, or pictures, capture the full scene and hence can include significantly more information than traditional videos. Further, by utilizing Amaze360, our head-mounted virtual reality application (also presented in Chapter 4.1 Preparing for maintenance), additional information can be embedded in the videos and pictures to further support information sharing.

We produce omnidirectional videos by recording the scene with six GoPro 4 cameras attached to a Freedom360 mount, designed specifically for filming omnidirectional videos. The resulting six videos from each shot are converted into a 4k omnidirectional video using AutoPano Video Pro 2 and AutoPano Giga 4 software. If further editing is required, such as modifying the audio, this can be done normally with professional video-editing software such as Adobe Premiere Pro.

Speech-based interaction

Maintenance work requires use of the hands, and both carrying and using additional devices purely for reporting purposes is not reasonable. In order to support reporting while minimizing the need to use the hands, and also to enable on-site guidance during maintenance and inspection visits, together with Konecranes we have designed an interactive maintenance support system utilizing speech interaction.

The system enables the technician to synchronize maintenance and inspection tasks on a smart watch. When on site, the technician is able to report the conditions of the checked components using speech input into the system, following a predefined grammar. The system then repeats the recognized text using speech synthesis. If the system is confident in the recognition result, it gives the user information on the risks of the reported fault, and the recommended action to follow. If confidence is not that high, the system asks for a confirmation or correction. There is also a possibility to record comments as free-form speech, which will later be recognized, transcribed, and saved as text in the system. The real-time speech recognition is limited to a predefined grammar in order to optimize the speed and accuracy of the recognition. A dialog-like interaction between the technician and the system could be:

Technician: *"Hoisting wire rope is bent"*

System: *"New issue added, hoisting wire rope is bent or damaged. This poses a safety risk and recommendation is to replace."*

The system comprises a smart watch, a microphone headset, a smart-phone, and a laptop. However, the user has to interact physically only with the smart watch. In order to minimize the need to use the hands, physical interaction with the smart watch involves only browsing through some lists. Even triggering speech input does not require touching the smart watch, as the system listens all the time and catches pre-defined keywords from the audio, although the recognition may be turned on and off to allow conversations with other people. For the prototype phase, a laptop computer is used to act as the speech recognition server, meaning that it receives the speech audio, performs the speech recognition, and sends back the recognition results. An Android smart-phone performs the communication between the other devices, has a state machine, and is responsible for audio streaming and text-to-speech synthesis.

Custom optical character recognition (OCR) reader for maintenance value reading

Maintenance work often includes logging different readings of maintenance panels. Some of these panels are internet enabled, but often they are not and reading them has to be done manually. We studied a case where the objective was to read different values from the maintenance panel of a crane to automate the value reading from the LCD screen. In addition to automate the value reading, this would also make possible to present the meaning of the values for the maintenance worker and to guide him/her to do the actions needed as described in section 4.2 (Contextual guidance).

The problem was that basic Optical character recognition(OCR) readers were unable to read from the small display, which contains fonts that were only 3–5 pixels wide. A program was created for testing purposes for a tablet device to read these values. The program has small rectangle box in the middle of the screen and user needs to adjust the camera so that the LCD screen fits inside that box. The program down-scales the captured images and converts them to a black and white images. After this, pixel arrays from the images are compared to the actual fonts which are stored inside the program. Finally, the program determines if those captured values are valid and displays them on the screen. When the program finds valid results, it locks that result to the screen and displays the result with green color.

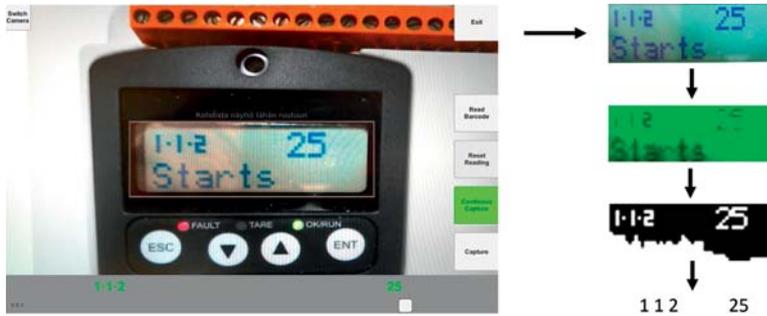


Figure 2. Automated value reading from a maintenance panel of a crane

This program was tested in different conditions to determine if it could give valid results in varied conditions it would encounter in the field where these maintenance panels are located. The program was able to read the screen on decent conditions where lighting was acceptable. It encountered problems when used in poor lighting because of the poor LCD backlight implementation. Also glaring caused some problems.

Lessons learned

Wearable solutions can shorten the time spent on secondary tasks (e.g., reporting and browsing manuals) during maintenance tasks. The technicians who tested the wearable data-gathering and sharing solution agreed that online and on-site reporting would be very useful in their work. Another benefit is that maintenance technicians can have their hands free, so that they can focus on performing repair tasks. However, wearable devices such as smart watches have a limited screen size. Touch-screen or gesture-recognition input methods may also create constraints in demanding operating environments. Challenges can also arise from the simultaneous use of multiple devices and the selection of the best technology combination for maintenance work.

Recording an omnidirectional video of a task, such as a maintenance procedure, presents many challenges. Positioning the camera(s) so that the procedure can be captured in enough detail requires planning, especially since the recording equipment cannot obstruct the technician conducting the maintenance. The location can also present obstacles for the recording of omnidirectional videos. For example, tight spaces, large crowds of people, or bad lighting conditions can affect the end result greatly, and can make the presentation of the task unclear. Hence, communicating and planning the recording process with the involved technician(s) is important. It is also notable that recording the video may not be enough, as it is difficult to capture the small details of a task on video. For instance, the camera may not see all the small pieces that

the technicians may need to manipulate. Therefore, the importance of additional embedded information is further emphasized (see Chapter 4.1 Preparing for maintenance).

For speech recognition, the most obvious challenge in the field is background noise and decreased speech recognition accuracy. To respond to the challenge, a high-quality noise-absorbing microphone should be used, but solutions in the interaction design may also be utilized, dividing the responses to recognition results according to the recognizer's confidence. The least confident results may be rejected, while those failing to be confident enough may generate a dialog asking the user if they meant what was recognized, and providing a chance to give a simpler correction command. Another major challenge is recognition of free-form speech, especially when dealing with a language that is marginal from a research perspective, or a language that is troublesome to recognize accurately because of word conjugation, such as Finnish.

Even if maintenance targets are increasingly internet connected, the life cycles of machines are long and there are still many maintenance targets where readings of maintenance panels need to be done manually. Automating this work will ease reporting work for the maintenance technician, and it can also generate a link to contextual guidance as described in section 4.2 (Contextual guidance).

In order to truly utilize wearable devices, omnidirectional content, or speech-based interaction in an industrial context, as in routine practices and tools, rather big challenges still need to be tackled. First of all, equipment with industry specifications is not yet available for testing. More importantly, in order to utilize omnidirectional content, the whole production process has to be organized and cost efficient. This means that recording, postproduction, and usage all have to be optimized and automated, so that they require minimal manual work.

CASE Bronto Skylift: Mobile service technician

Jouni Törnqvist/Bronto Skylift

Background and objective

Bronto Skylift is the global market leader in truck-mounted hydraulic platforms. We design, manufacture, sell, and service appliances for rescue and firefighting, as well as for construction work. Our product range includes approximately 50 models with a range of 17 to 112 meters working height. The advanced modularity also enables numerous client-specific modifications. During the past 50 years, we have delivered more than 6,700 platform units to fire departments and industrial customers across all continents, in more than 120 countries.

Bronto Skylift has been a pioneer in digital services in the hydraulic platform business. Since 1999, all platforms have been connected to the GSM data network, and since 2013, all new platforms have been connected to the Internet. Direct remote access to a platform's control system has increased the quality of service, shortened down time, and saved money.

In the DIMECC S-STEP program, we had an opportunity to study new technologies, especially omnidirectional (360°) video and augmented reality (AR) solutions. Linking information from various sources, sharing information, and field reporting directly to the service server were also part of the studies. The target was to take the maximum benefit from the possibilities of Android tablet PCs and mobile phones in field service, and to improve the efficiency of service visits.

Results

The DIMECC S-STEP program gave us insight into omnidirectional video and augmented reality (AR) technologies in field use. We also studied and developed solutions that would help the service technicians to get service done in a single visit, and to report findings directly to our server without traditional paperwork.

Research work proceeded in two phases. In phase 1, we did field studies together with the University of Tampere TAUCHI unit, to understand the possibilities of omnidirectional video technology and to create simple service instructions added using hotspots and virtual reality elements. Together with 3D Studio Blomberg, we developed an augmented reality solution to show different kinds of features of the working cage. The theme for phase 2 was collecting information from various sources, integrating the information, and sharing the information with field service technicians.



Impacts

At Bronto Skylift, the research done in S-STEP has resulted in different types of impacts. The service technicians have been very satisfied with the amount of information we can offer them before and during the service visit. They also feel that field reporting is now much easier without additional paperwork and email. Actually, it is quite surprising how easily they have started to use the possibilities of the new technology. Good field reporting has also increased our awareness of our strong and weak points, and this is excellent information for quick reactions and future engineering. In general, communication between Bronto Skylift's engineering department and service area is now on a new level.

The newest technologies, like omnidirectional videos or augmented reality solutions, are felt to be hi-tech solutions that have more of a business effect (something new for marketing) than they are practical service tools for everyday use. Both technologies offer a lot of possibilities, but to create good quality material with today's tools is very time consuming.



Figure 1. Truck-mounted hydraulic platform by Bronto Skylift

Phase 1: 360° visualization and AR

In phase 1, service technicians were interviewed and maintenance work tasks observed. The possibilities of omnidirectional videos were tested in practice by choosing a couple of simple service cases, like changing and calibrating a sensor. The videos were created together with service technicians and tested with other service technicians in real situations.

An AR demo was created, together with 3D Studio Blomberg, for an Android tablet PC, to demonstrate the parts of a working cage, possible service points, and the operation of different kinds of options. This AR demo was shown at the INTERSCHUTZ exhibition in Germany in 2015, to get immediate feedback from the service organization and from Bronto Skylift customers. The feedback was mostly positive.

Phase 2: Information flow

The theme for phase 2 was collecting information from various sources, integrating the information, and sharing the information. The principle is shown in Figure 2.

Bronto Skylift platforms use a common failure code structure in every platform. When the control system senses a failure in the control system, in the hydraulic system, or in the mechanical structures, it automatically sends a failure code to the service server. This principle has been used for several years. In phase 2, we linked the failure code, all the prepared material, old field reports, black box data (electronic fingerprints of failure), previously analyzed results, and spare-part offering to offer a quick solution to the service technician to solve the problem in the field. When the service technician has solved the problem and reported the findings using text, photos, videos, speech, and/or sound samples, the new information is automatically linked to the failure code for future use. All the reports can be created using an Android tablet or a mobile phone, and the report is automatically transferred to the service server.

Lessons learned

AR and omnidirectional video technologies have a lot of possibilities, but to get high-quality and practical material for service operations, it is also very time-consuming, especially for products that are heavily tailored or have lots of different variations.

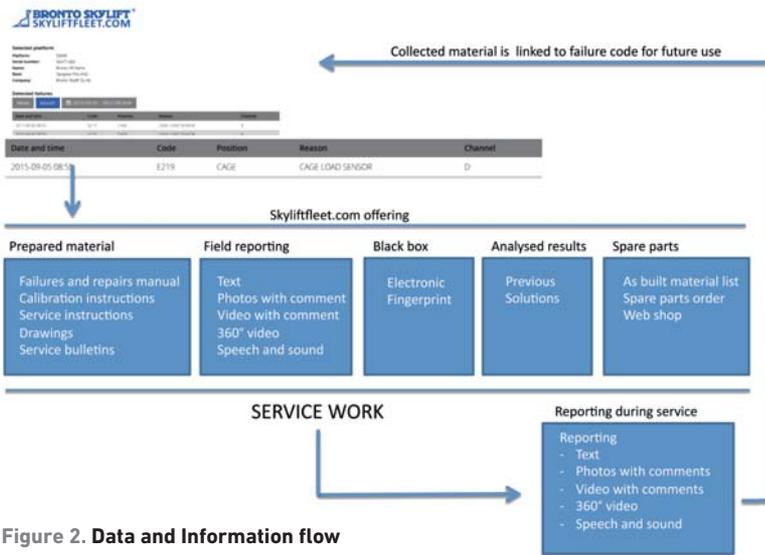


Figure 2. Data and Information flow

Outdoor use of AR solutions is very challenging. The position of the sun, rain, or clouds changes the amount of light and creates shadows in different positions. Getting good contact with the target object is very challenging without special reflectors or markers. When environmental conditions are good, the final result is very useful, and we got a lot of positive feedback from our customers and service technicians.

Omnidirectional videos have potential, especially in cases in which the service technician needs to get preliminary information on the structures of the machine, such as how the telescoping boom is operating. The 360° visualization complemented with informative hotspots gives the service technician a good vision of the forthcoming work. Omnidirectional video technology is also excellent technology for training.



"Today's machines are a complex combination of different kinds of technologies, and the need for information among service technicians is increasing every day. For the same reason, reporting from the field is more and more time-consuming. In this project, we developed a new way to collect and share context-sensitive information using a single device. S-STEP program has been a real success story, and we will continue the development in the future"

Jouni Törnqvist, R&D Manager, Bronto Skylift

Contextual social media

Introduction

In our interviews with maintenance technicians, user-initiated knowledge sharing was often described. The technicians, for instance, described how they often write down notes for the next maintenance visit, for example on the cover of the machine to be repaired. The notes may indicate special conditions that should be taken into account, such as “due to the humidity of this environment, instead of manual recommended settings, these are better:” The notes serve both the maintenance person for their next visit, and their colleagues.

Organizations are increasingly adopting social media technologies to enable personnel to interact and share knowledge. Denyer et al. (2011) point out that mere installation is not enough: success in adoption and effectiveness in full exploitation will be dependent on reconfiguration and redesign of the whole socio-technical and managerial system, coupled with a heightened sensitivity in implementation. Huang et al. (2013) found that, at its best, social media can add multivocality, increase reach and richness in communication, and enable simultaneous consumption and co-production of content.

Contextual media, or ubimedia, is a concept in which media files are embedded in everyday objects and the environment. This facilitates easy access and storage of, for example, text, video, and audio related to the physical object in question (Kaasinen et al., 2010). Contextual social media is characterized as follows:

- It is created and shared within a user group.
- The relevance of the information is assessed based on peer feedback (likings) and the social media reputation of the information provider.
- The information is connected to a certain context, such as the machine to be repaired.



Figure 1. An example of accessing contextual social media during a maintenance task ©Konecranes

The user feedback for contextual social media in the S-STEP project was very encouraging, even if the evaluations until now are only based on concept descriptions. In the following, we first describe VTT's AR SoMe solution, which will be piloted in S-STEP. We also describe the initial feedback from maintenance personnel based on a focus group in which AR SoMe and many other knowledge-sharing solution concepts were assessed by maintenance professionals.

AR SoMe solution

The ALVAR Augmented Reality tracking library recognizes target objects based on one or more reference images. The reference image(s) are used to automatically identify the target object, but also to track the target object, so that it is possible to add virtual content that stays “glued” to the object in the video view.

In the AR SoMe implementation, each target object is automatically provided with a unique hashtag (e.g. #AR5673fd12c2095). You create a new target object by taking one or more reference frames. When you view this same object again, the software recognizes it by comparing the visual appearance to the reference frames, and then returns the associated hashtag.

This makes it possible to attach social media messages to that particular object just by including the appropriate hashtag in that message. When you view the target object, you can automatically see the attached

posts, or add new posts, for that particular object. Of course, the same messages can also be browsed and searched without the video view, using a more traditional text interface.

AR SoMe can use traditional social media sites like Twitter or Facebook, but it works just as well for any message platform, including possible chat rooms that are internal for the company.

Initial user feedback

In the focus group, we presented the AR SoMe concept to the participants with a video that illustrated using AR SoMe in an office environment. Even though the environment was different, the participants easily understood the concept and could imagine using it in a maintenance context. The evaluations took place at Konecranes with a focus group that consisted of four maintenance professionals, as well as design team members. All the maintenance professionals had a long work history in different maintenance positions, and three of them were currently in managerial positions.

The professionals liked the idea and the possibility to share not only text, but also video or voice messages. They saw that contextual social media could network maintenance technicians in a natural way, and could replace separate networking applications that have not been well adopted in the workplace:

"You could easily see that Matias from Sweden knows how to change XYZ (a spare part)."

SoMe data could complement official maintenance documentation with practical knowledge from the field. The professionals also realized that the knowledge could serve not only the maintenance object, but also similar objects elsewhere:

"Someone could tweet that these settings work well on the brakes, and another technician could see the advice for other similar brakes right away."

The professionals saw that the SoMe concept would facilitate getting actual feedback from the field. Currently, the feedback is unconnected, and the SoMe concept could facilitate integrated information and connect the information to relevant maintenance targets. The concept could activate technicians to become active information producers instead of passive information users.

"That is where the actual information is, not on the designer's table."

The professionals suggested that the hashtag could also indicate who should be informed about the message, as in #safety or #quality. In this way, the message could also reach the official organization.

The professionals pointed out the threat that the shared information may be wrong. A technician may believe that he knows the issue and may unintentionally share the wrong advice. However, they thought that the network would help in assessing the information:

"When you know the guy, you know to what extent you can rely on their advice".

The professionals were a bit worried about missing some important SoMe information:

"What if I do not notice the SoMe info?"

"When going to the crane, do I have to study it thoroughly just to make sure that I do not miss any embedded messages?"

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Company impact

"On every day of the year Konecranes performs thousands of customer visits where technicians enter or access equipment data of various detail levels. Anything that can make their job safer and more productive, is of great interest and importance to us. Excellent user experience is mandatory to get technologies and tools widely approved and utilized by technicians. S-STEP project has already shown many feasible concepts worth of further development."

*Heikki Rekola, Director, Service Product Management
Konecranes*



CASE Konecranes: Mobile service technician

Joona Elo
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Background and objective

Konecranes is working in the large field of industrial maintenance services. We have several thousand service technicians working globally in crane and machine tool service. In our service process, it is essential to report and record service findings promptly. Sadly, this is not always possible, due to a lack of adequate software and tools, including poor network connections and challenges in the industrial environment.



In the S-STEP research, we had the opportunity to study new technology, especially wearable and augmented reality (AR) solutions. In the DIMECC S-STEP program, the overall objective for Konecranes is to improve the efficiency of service visits by identifying the equipment and system with the help of an augmented reality application. The efficiency of internal service processes is also part of the objective, by providing means to support work planning and information documentation during service visits. The program provided know-how in the application of augmented and virtual reality (AR/VR), multimodal interaction, wearable technologies, and new methods of knowledge processing for data.

Figure 1. © Konecranes

Results During the DIMECC S-STEP program at Konecranes, we studied and developed solutions that would help service technicians to perform maintenance and report findings more easily and more effectively. Research was divided into two phases. In phase 1, we concentrated on reporting and information sharing. In phase 2, the focus was on AR-enabled real-time contextual information.

Impacts At Konecranes, the research done in S-STEP has resulted in different types of impacts. It has raised awareness in the Konecranes Service business unit, and more widely in the company, that solutions that are considered nearly sci-fi are actually today's technology. The project has also created a good dialog between the Konecranes research organization and Service business unit when planning new areas for development. In general, the Konecranes Research and Innovation department's presence and influence on the service area has increased during the S-STEP program.



Figure 2. ©Konecranes

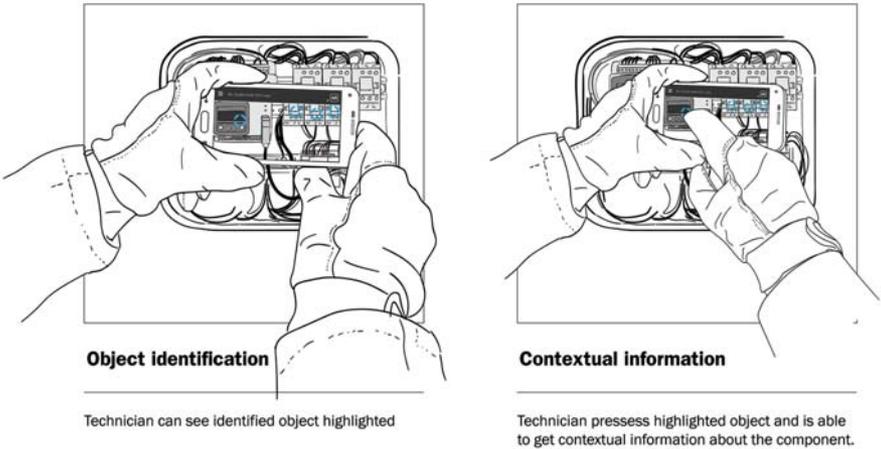


Figure 3. ©Konecranes

Phase 1: Feasibility demo

Service technicians were interviewed and maintenance work tasks observed. In phase 1, a feasibility demo application was implemented using an Android smartphone, Sony smart watch, and VUZIX head-up display. Kontakt-io Bluetooth beacons were tested for locating the correct subject of maintenance on the factory premises. With the demo application setup, technicians were able to document and report service findings. The created concept was tested in an industrial context with real end-users.

Phase 2: Real-time contextual information

The theme for phase 2 was real-time contextual information. The objective of phase 2 was to continue studying ways to improve the service technician's work and reporting with the help of AR technology and applications. Konecranes' most common industrial overhead crane, CXT, was chosen as the context of the study. By concentrating on CXT cranes, we are more prepared to create a solution that can be implemented globally.

VTT's AR SoMe (Social Media) concept was studied and developed in phase 2. AR SoMe provided a very promising platform and process for creating AR content and turning technicians from content consumers into content creators. Real-time tracking provided the means to study the benefits of contextual information and support for technicians to carry out their tasks. Other concepts have also been derived from the program, to include speech recognition for service reporting and a data input concept based on OCR (optical character recognition).

Lessons learned

The service technicians' attitude toward new wearable and AR solutions is positive, but because of previous experiences with immature technology used in the field, they are also cautious. Nevertheless, they do welcome technology and new solutions that make their work easier and more effective. Less time spent on reporting is a welcome goal for them, as well. The results show that there is a need for an advanced service tool. A hands-free information feed and context-sensitive guidance or content share are areas of great potential in Konecranes service, and should be studied more. By concentrating on the user experience, we are able to deliver such tools that really revolutionize the technician's work.



Company impact

"The S-STEP results show that there is a need for an advanced service tool. A hands-free information feed and context-sensitive guidance or content share are areas of great potential in Konecranes service, and should be studied more. By concentrating on the user experience, we are able to deliver such tools that really revolutionize the technician's work."

*Johannes Tarkiainen, Industrial Design Manager
Konecranes*

Providing situationally relevant information

Industrial maintenance is a key factor in achieving high availability and efficient operation in production. Maintenance work is becoming more knowledge intensive because digitalization makes more information available, but also because of the needs of versatile tasks and the servicing of more advanced devices. As maintenance personnel perform their tasks, they have supporting information available, such as work orders, maintenance history, diagnostics, and service manuals. Many of these sources are dispersed and often also incompatible, making gathering supporting information a laborious task in itself.

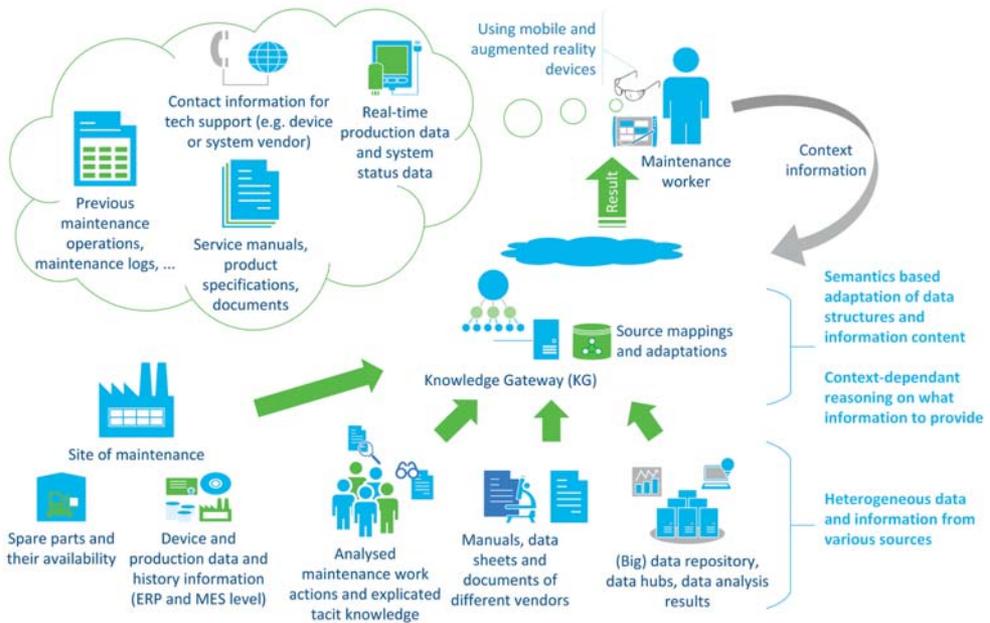


Figure 1. The concept of integrating heterogeneous data sources using a semantics-based layer with information models and contextual reasoning, to automatically provide situationally relevant information. (Hästbacka et al., 2015)

The objective is to have situationally relevant information to support the current maintenance task for the maintenance personnel. A concept of a knowledge gateway has been developed that integrates different information sources and automatically provides the relevant ones with minimal user interaction. For this, semantics-based information modeling techniques have been developed to describe the information, as well as to carry out reasoning on what information should be provided. This information could then be provided through various mobile or augmented reality interfaces, directly to the maintenance person.

Semantics for categorization and contextual reasoning

Maintenance situation context modeling

The meaning of context is very much dependent on the application area and each setting. The scope of the context needs to be defined for the maintenance application domain of the knowledge gateway (KG) system. The aim is to provide relevant situation-dependent support information for field service personnel (FSP) during maintenance work. Contextual information is exploited in combining, filtering, and accessing information in the primary knowledge base (KB), as well as in providing links to appropriate external services. In this approach, the basic concepts of the context model and high-level categorization are based on the Situation Assessment Context (SAC) model defined by Gundersen (2014).

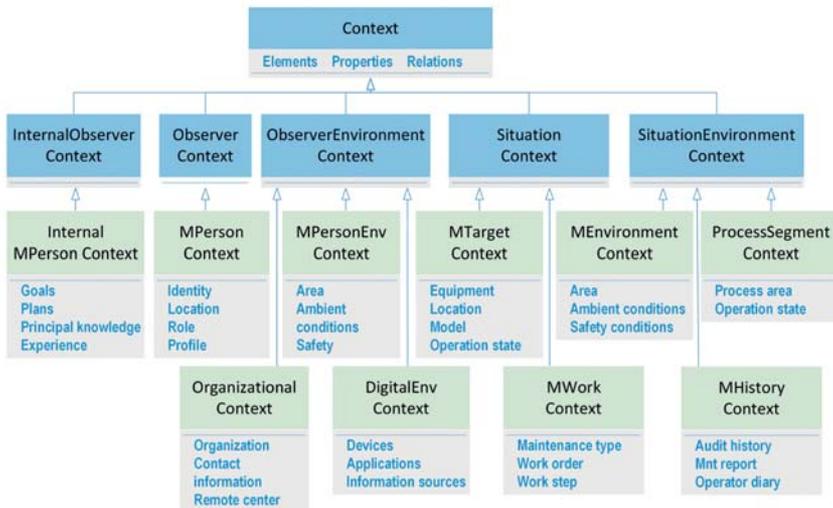


Figure 2. A class diagram presenting Maintenance Context classes (two lower rows) in the Situation Assessment context hierarchy (two upper rows). Some examples of the possible elements of the context classes are listed as class members

The SAC hierarchy, with five element categories, is extended and specialized for the maintenance operations domain by ten new categories, represented in Figure 2 as Maintenance Context (MC) classes. As a result, the overall operational context model consists of ten contexts with different sets of elements, which represent different aspects of the total knowledge content. Therefore, these different contexts can provide a different contextual view of the KB. These MC classes are the following: *Internal MPerson*, *MPerson*, *MPerson Environment*, *Organizational*, *Digital Environment*, *MTarget*, *MWork*, *History*, *Environment*, *Process Segment*.

In addition to maintenance domain-related context elements, many of the commonly used context dimensions, like *agent*, *location*, *identity*, *activity*, and *time*, have a corresponding representation as an element or as an element attribute in many of the context types.

The context model ontology

The context model ontology consists of two types of concepts: a small set of basic upper-level concepts (prefix letter C in Figure 3) and an extendable set of domain-related concepts defined as specializations of the upper-level concepts. The maintenance domain concept names are mostly adopted from the Mimosa OSA-EAI model (Mimosa, 2014). Elements can be characterized by attributes and associated with binary relations to other elements.

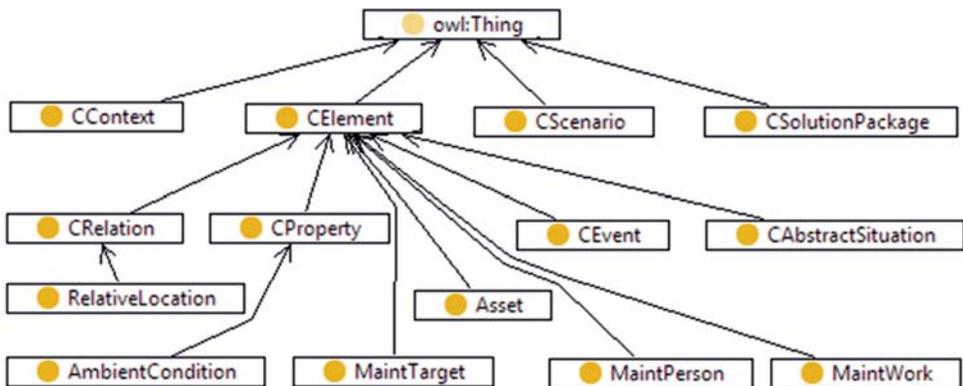


Figure 3. The upper-level class hierarchy (prefix C) of the context ontology, extended with some of the domain-specific CElement subclasses

Contextual reasoning

Contextual reasoning is carried out mainly at a high conceptual level in the KG. This capability is implemented by SPARQL Inference Notation (SPIN) rules embeddable in context and element classes, enabling an object-oriented style of modeling. Four basic kinds of rules are used in the context model:

1. *Element construction rules* are used to initialize the main attribute values of the created element instances, such as references to the primary information objects in the KB.
2. *Information filtering rules* are used to select a relevant set of information objects in a solution package to be provided for FSP. What is relevant support information depends on the context, such as the current work phase and expertise level of FSP.
3. *Modification rules* are used to update element values. The situation rules explained above belong to this category.
4. *Constraint rules* can be used to validate element values before other rules are executed.

The context-related support information is provided to FSP as a solution package, which is an aggregated package object containing guidance information for their work, and which can be provided, for example, using a mobile device or an augmented reality interface.

Conclusion The developed concept was prototyped using artificial examples to evaluate the concept and the developed models and reasoning mechanisms. The prototyping showed that this kind of modeling and reasoning can be built on top of existing systems to provide relevant information in an automated manner. This requires that mappings and integrations to those existing source information systems are developed, which is an active research topic on its own, but not directly addressed in this study. For compatibility reasons, acknowledged standards should be promoted, and the information models built were developed with this in mind. It is also believed that lightweight information models and reasoning technologies such as RDF and SPIN could be very useful without all of the computational complexity involved in full-scale Semantic Web technologies.

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CASE 3D Studio Blomberg: Case Vamp AR

Background and objective

3D Studio Blomberg (3DS) has experience of industrial visualization since the company was founded in 2001. Ever since, the vision has been to efficiently provide visualization solutions that promote efficiency and quality in industrial applications and processes.

Emerging technologies like augmented reality (AR) and virtual reality (VR) provide completely new possibilities in human-machine interaction (HMI), as well as in process efficiency.

3DS realized the need to study implementation possibilities with a short lead-time. By acquiring knowledge of existing mature state-of-the-art technologies, and identifying established players and networks, 3DS will enable the extraction of explicit knowledge by providing AR solutions in human-machine interaction.

Pontus Blomberg

3D Studio Blomberg Ltd

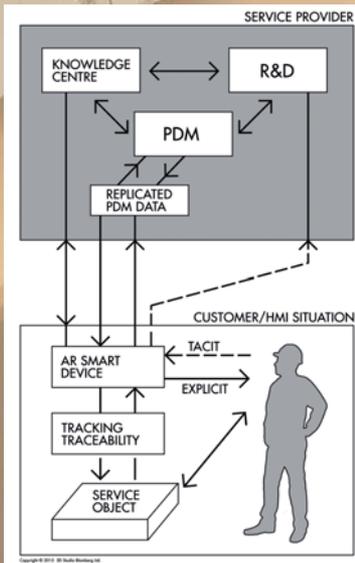


Figure 1.
With augmented
reality solutions,
explicit information
can be made situa-
tionally available

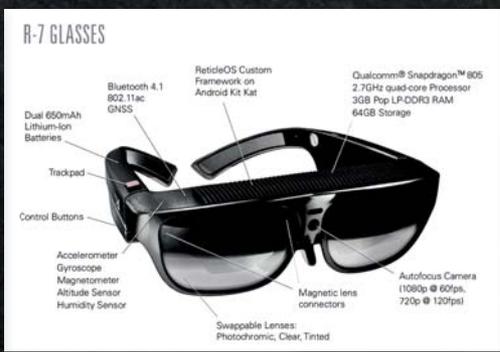


Figure 2. The 3DS/Vamp showcase

The Vamp AR S-STEP showcase was carried out together with Vamp Oy, a Finnish subsidiary of the Schneider Electric Group, but the project was performed independently by Vamp Oy in cooperation with 3DS. The project's goal was to identify, track, and provide situationally relevant and up-to-date information by utilizing existing state-of-the-art technologies. A protection relay by Vamp (Figure 1) was used in the project as the showcase platform for augmented information.

Results During the S-STEP project, 3DS gained knowledge of existing leading global players in the AR and VR field of business, both for software and hardware.

3DS successfully implemented the identification, tracking, and display of situationally relevant data by utilizing commercially available products (software/hardware) on the Vamp 300 protection relay.

3DS still sees the need to gain knowledge about real-time connections to current information in PLM systems. This will enable efficient communication from PLM and business systems to the field and the end-user.

Impacts 3DS has gained experience of, and earned a presence in, leading global technology networks, contributing to future business possibilities in both the short and the long term.

Lessons learned Implementation of AR and VR in industrial processes, enabling digital transformation, is facing long lead-times. This is due to an incomplete technology infrastructure, a lack of interfaces to product and business systems, and the fact that manual work phases are still needed. Industrial organizations also need to develop an overall understanding of the technology infrastructure (i.e. IoT), as well as to start working differently. This will take time and should be part of the overall business strategy, which will impact the agenda, culture, and overall understanding.

Enabling technologies

There is a lot of activity on the market related to AR and VR. Some is hype and some is promising and long-term. The huge amount of activity and hype creates business opportunities when the big players move into the field, where leading AR and VR companies act as "bait" for the big players. All of this makes it even more difficult for both industrial organizations and solution providers (such as 3DS) to build long-term relationships. However, these new technologies will "change the world," and it is crucial to be able to make decisions in order to move forward.

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