Proceedings of the 1st Annual SMACC Research Seminar 2016

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Jussi Aaltonen, Riikka Virkkunen, Kari T. Koskinen & Risto Kuivanen (eds.)

Tampereen teknillinen yliopisto - Tampere University of Technology

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Tampere University of Technology

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FOREWORD

The Annual SMACC Research Seminar is a new forum for researchers from VTT Technical Research Centre of Finland Ltd, Tampere University of Technology (TUT) and industry to present their research on the area of smart machines and manufacturing. The 1st seminar is held on 10th of October 2016 in Tampere, Finland.

The objective of the seminar is to publish results of the research to wider audiences and to offer researchers a new forum for discussing methods, outcomes and research challenges of current research projects on SMACC themes and to find common research interests and new research ideas.

Smart Machines and Manufacturing Competence Centre - SMACC is joint strategic alliance of VTT Ltd and TUT in the area of intelligent machines and manufacturing. SMACC offers unique services for SME`s in the field of machinery and manufacturing – key features are rapid solutions, cutting-edge research expertise and extensive partnership networks. SMACC is promoting digitalization in mechanical engineering and making scientific research with domestic and international partners in several different topics (www.smacc.fi).

Tampere 2nd of October, 2016

Editors

I Engineering Asset Management

1. INTELLIGENT ASSETS AND SMART DATA-ORIENTED SERVICES AS A SOURCE OF COMPETITIVE ADVANTAGE

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ABSTRACT

Recent academic research has paid particular attention to how digitalisation disrupts current business models and business environments. Furthermore, servitization has gained significant attention. Currently, industrial internet based services have been insufficiently integrated into customers' business processes and the potential of digitalization has so far not been fully exploited. The goal of the SmartAdvantage research project is to enhance value creation opportunities for industrial ecosystems by developing novel approaches and business models for digitalised asset management.

SmartAdvantage research project is a part of a joint research project, combining the efforts of research organisations and industrial partners. The parallel project structure provides an opportunity for sharing experiences, benchmarking activities and learn from each other as well as for research institutes and industrial partners to work efficiently together by combining their expertise. The results will support companies in creating new offerings and capturing business opportunities. SMACC R&D community will be used to disseminate and exploit the results.

INTRODUCTION

Digitalization has already transformed many sectors of industry and society, for instance media, banking and communications. This transformation is expected to continue further (OECD 2015, WEF 2014). Manufacturing industry will be transformed greatly by enhanced collection, analysis and utilisation of information through developments and reduced costs in sensors, wireless networks, data analysis and the whole IT systems (e.g. Thomas et al. 2014). These developments offer opportunities for creating completely new combinations of products and services.

Companies are in different positions and levels of preparedness with respect to the digitalisation. There are companies with earlier unsuccessful experiences and pilots, companies just now taking the firsts steps by for instance building monitoring capabilities for warranty period, and companies considered as forerunners with offerings for e.g. remote asset and fleet optimisation. However, there is a significant unrealised potential that needs to be studied further.

Engineering asset management, defined as "coordinated activities of an organization to realise value from assets" (ISO 55000 2014), is an area of great potential for digitalized services and there are already several examples of digital asset management based services in the literature and in companies (e.g. Lee et al. 2015, Medina-Oliva et al. 2014). Due to the recent development in wireless technologies and growing interest towards industrial internet, the amount and variety of available data has grown rapidly in industrial applications. Often the companies are familiar with the potential provided by the available data but due to the novelty of the availability of such amount and variety of the data, they do not have the know-how on how to manage the data efficiently nor how to discover the valuable information from the data (Mishra et al. 2015, Padiya et al. 2015).

METHODOLOGY

SmartAdvantage project's main research question is: How can networked industrial companies develop and introduce new value-adding, data-based and knowledge-intensive services for supporting customers in the management of their assets in complex business and production environments? The research has been divided into three main themes: 1) business models and asset management approaches; 2) data-driven services; and 3) information management. The work is planned and conducted in close co-operation with companies and their networks, to strengthen the emergence of practical solutions that steer the companies towards digitalized asset management.

The study is divided into the following interrelated parts that have different methodological approaches:

- WP1 Enablers, barriers and visions for digitalisation in machine and productions systems sector.
- WP2 Data management and embedded intelligence in complex industrial systems through data-driven decision making.
- WP3 Knowledge-intensive and integrated asset management business models.
- WP4 Testing the methods and tools in case studies.

In WP1 the current state of digitalised asset management is analysed and future vision of asset management services and their business models is created. WP1 consists of literature reviews, interviews and roadmapping work involving research organisations, case companies and their networks. Furthermore, case-specific analyses and an in-depth cross-case analysis will be carried out.

Work packages WP2 and WP3 adopt a constructive research strategy combined with case research whereby the intent is to develop and test the business models, operational practices and analytics approaches enhancing the digital asset management. WP 2 consists of literature reviews of the existing solutions for data management in industrial internet applications and studying the company cases for establishing the need and the suitable approaches for the data management and data analytics. In WP3, concepts and frameworks for future integrated asset management services, and methods, models and KPI's for managing service levels in complex multi-actor service ecosystems are created.

WP4 focuses on the testing and experimentation with the developed construct, and its validation across cases. The elements of the overall results for digital asset management will receive empirical validation through the specific company cases, as well as the research teams' creative cross-disciplinary collaboration.

EXPECTED RESULTS

SmartAdvantage yields beyond-state-of-the-art knowledge on how data can be converted into valuable formats, integrated to decision-making and business models. Practical results of the SmartAdvantage project include: 1) a managerial guidebook for exploiting the potential in digitalisation for asset management; 2) company case-specific development, directed by generic objectives and objectives to spread out the results for a variety of applications; 3) approaches, methods and tools to digital asset management services; 4) publishing research results in project seminars, conferences and in scientific and professional journals according to open access principles; 5) dissemination of the results through teaching and via commercial assignments; 6) disseminating the results among the SMACC company network; 7) research material for doctoral dissertations; and 8) new, prioritized prospects for forthcoming research.

CONCLUSIONS

We conclude that companies should take a broad view on digitalised asset management and develop their service portfolios by considering the following levels: business models and asset management approaches, data-driven services and information management. It is recommended that the requirements for the technology solutions are derived from the business needs, which reflect the understanding gathered from customers' business and production environments.

SmartAdvantage supports the development of effective approaches for data exploitation, customer value driven smart asset management services and business models in Finnish companies to gain access and competitive advantage in global markets.

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2. ALLOCATION OF MACHINE FLEET DATA PRE-PROCESSING

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ABSTRACT

The data that is available from the machines often includes process data, measured attribute data, maintenance data and data about operating environment. When dealing with data collected from the fleet of machines including numerous units that are often distributed to a broad area, the amount and diversity of the acquired data is huge. That is why there is a need for data pre-processing in order to utilise the available data efficiently. The data pre-processing is executed either on the operating site, right where the data is collected, or after the data transmission in the centralized database. However, variety of factors, such as on-site computational power, connection for data transmission, the application in question and the intended use of the data, have a huge effect on where the data can be pre-processed. In this paper we propose a general framework for determining the most efficient way for allocating the data pre-processing considering the most significant challenges for data pre-processing in machine fleet applications.

INTRODUCTION

The utilisation of available data for providing holistic data-driven services for group of distributed machine units, i.e. the fleet of machines, have been a major interest in the research community due to the recent development of Internet of Things. The data that is acquired from multiple machines that are operating in various environments and are used by different users for various purposes causes multiple issues [1, 2] and there is often a need to pre-process the data in order to utilise it efficiently. In general, the data pre-processing can be executed either on the operating site or after the data transmission in the centralized database and by suitable allocation of the pre-processing some challenges related to fleet data can be avoided. However, some of the features that cause a need for pre-processing also restricts the allocation of the data pre-processing. In this paper these features are introduced and the effects they have on the allocation of pre-processing tasks are studied based on the interviews with the production and construction machine manufacturers. By the means of these studies, a general framework for allocating the data pre-processing efficiently in fleet applications is proposed.

MACHINE FLEET DATA

The fleet of machines consists of multiple distributed machine units. The machines are often distributed to a multiple customer that each use the machine in a different manner in different operating environments. Furthermore, especially with complicated production and construction machines, each machines are often modified to meet the customer requirements. Therefore, the volume of available machine fleet data is often huge and there are multiple sources of inconsistency with the data. In many applications, the nature of the fleet data causes a need for process the data before utilisation of the data in order to gain meaningful results.

Due to the huge data volume, metadata that describes the context of the data plays a crucial role in data management and the methods for automatically checking the metadata and adding missing metadata are often needed in fleet applications. Huge data volume also causes a need for data compression and reduction methods that provides tools for storing and transmitting the data more efficiently. Furthermore, since the data is often filled with inconsistencies due to the different uses and operating environments of different machines, the methods for removing inconsistencies and integrating the data from different sources are needed.

THE ALLOCATION OF DATA PRE-PROCESSING IN FLEET APPLICATIONS

In most applications, the data pre-processing is executed on the operating site, after the data transmission in the centralized database or, in some cases, the pre-processing tasks can be divided to both locations. The efficient allocation of the pre-processing is a crucial task in fleet applications, since there are multiple issues related to the location of data pre-processing tasks when dealing with huge volume of data. It is especially useful for machine manufacturers when they are designing the machine and data acquisition system because most of the issues related the allocation can be avoided by efficient proactive design.

The on-site pre-processing is useful in applications where the quality of the connection for data transmission is low or the transmitted data is charged by the amount of the data. This is because it provides tools for compressing the data before transmitting it. Furthermore, creation of consistent metadata is far easier on the operating site since there is data from one source that can be easily identified. However, when the machines are operating in rough environments or otherwise there is no possibility to install expensive and more efficient data processing equipment, the on-site data processing capacity might be limited.

Centralized pre-processing is efficient when there is a need for significant data pre-processing due to vast amount of noise and outliers or multiple sources of inconsistency since the data pre-processing capacity is often very high. With the centralized pre-processing, the context of the data plays also a crucial role because the data is collected from the multiple sources and if the context information is missing or incorrect, it might be impossible to utilise the data for certain purposes. Furthermore, the vast amount of data has to be transmitted to the database before the centralized pre-processing, which is challenging if there are problems with connection for data transmission.

A FRAMEWORK FOR ALLOCATING THE DATA PRE-PROCESSING

The various application-specific factors play a crucial role when designing the most efficient allocation of the data pre-processing in fleet applications. Therefore, a framework for evaluating the suitability of each alternative based on the application is needed for helping the machine and data acquisition process design personnel to focus on the main issues. The framework proposed here includes five steps that are used for gaining the crucial information about the process (Fig. 1).

Figure 1. A framework for application-specific allocation of the data pre-processing

At first, the goal is to specify the application in order to create throughout understanding about the machines, their possible usage and operating environment. With throughout understanding about the application, it is possible to focus on the issues with the data processing and transmission that could cause restrictions for allocation of the data pre-processing. Once the application and its restrictions related to allocation are determined, the advantages and drawbacks of each alternative can be studied in order to evaluate the suitability of different locations for data pre-processing in this context. Furthermore, the there is need to assess the risks and challenges that could occur when installing and using the equipment for data pre-processing. The throughout consideration of the questions related to each of the four steps shown, provides complete information for making the decision for efficient allocation of data pre-processing considering all of the relevant application-related factors.

CONCLUSIONS

The paper stated a need for data pre-processing and the importance of the allocation of the pre-processing tasks in fleet applications where the data from the multiple sources is utilised. The features that cause challenges for the allocation of the pre-processing were discussed in order to create a framework for deciding the allocation of the data pre-processing in fleet applications. The future work includes more throughout development and the verification of the framework with real-world test cases. The goal is to create a general framework that performs exquisitely with the variety of fleet applications.

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3. ACCELERATED LIFE CYCLE ESTIMATION (NEM) PROJECT AT TUT

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ABSTRACT

The pain dot of the Finnish investment industry is the small volumes and a wide supply of different products in the class of the world. In the component acquisitions this often leads either to the making of the compromises at the expense of product properties, over dimensioning of the product by raising the price of the product or to unpredictable reliability problems. Increase in the share of an information technology and communication technology (ICT) in the form of automation, sensors and intelligent control systems the reliability demand of components tightens to the products. Due to the changes in the society the operating conditions of machines are changing continuously. Several trends such as changes in the operation environment, demands on user centred operation, energy efficiency, environment demands, modernizations and recyclability. For the predicting of the life time of components enough knowledge does not exist at the moment. New methods must be found for the anticipating of the lifetime.

RESEARCH IDEA

The reliability has been based on a long experience of the old components, into use of the over dimensioning and on too long field testing periods and too uncertain results within launching during the products. It is clear that with old methods it is not done any more in the competition.

The efficient utilizing of the new technology raises in a new light old concepts which have even worn out. The new approach makes possible from the manufacturer's, supporter's and user's point of view the control of total expenses dating from the times of the service life of machine investments and device investments. The starting point for a designer and manufacturer is the convertibility and adaptability of the machine to the changes required by the conditions and an opportunity for the modernizing of the product. A cost-efficient lifespan in which the planning of structures and use on their limits combine is obtained as a final result. The better control of the lifespan facilitates the flexibility of the production through the components which are more reliable. This operation also makes possible the service work which is in accordance with the real use history of the machine. The user centered control of the load which is in accordance with the real operating mode of the machine makes possible to the usability of the evaluation of the use which is more efficient than before and of its effect.

With the help of the control of the lifespan of the product PLM (Product Lifecycle Management) an attempt is made to control all the information and planning processes which are related to the product mainly with the help of software applications. Thus the accelerated definition of the lifespan of the product can be read as one part of a PLM process. With the accelerated definition of the lifespan an attempt is made to gather the necessary information which can be used for the follow-up and prognosis of the lifetime of the product with different methods. The objectives can be for example the optimization of costs and the increasing of reliability and safety. The essential factors in the accelerated definition of the lifespan are:

- acquisition of real-time multi parameter data - the slowness of the cumulating information is removed
- anticipating of the effects of operating modes - the variation of the use of the machine is taken into consideration
- feedback of the data in to earlier states - functions can be adapted

The idea in the research is illustrated in Fig. 1.

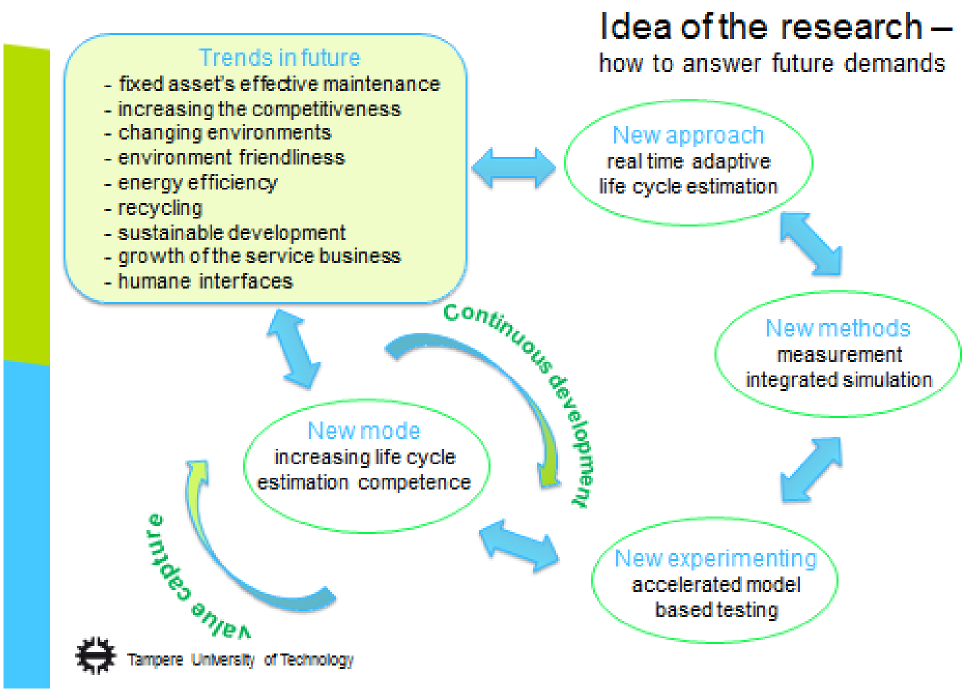

Figure 1. The idea in the research work in NEM project.

TARGET OF THE PROJECT

The general objective of the study is to form a life cycle knowledge and testing competence forum based on the whole life cycle of the product. In the testing and simulation methods the it is taken into consideration the effects caused by the use of the component in environments which deviate from the planned conditions. Use and useful life time definition of a machine, it is established in realistic estimates of the effects of loads by adaptive methods.

GENERAL GOALS

- To create TUT expertise and testing competence to cover the whole product life cycle by putting together a forum. This means:
  - cooperation with industry and other research institutes
  - arrange technology days and seminars
  - Machinery Life Cycle Forum – MLCF
- Generate new knowledge and competence in the areas of life cycle estimation and accelerated testing. Through university research to join the knowhow of university and the knowhow in industry of today. This means:
  - deep cooperation with industry

- To bring the examination of the whole life cycle as a linking factor in university teaching and research work. This means:
    - deep cooperation between university laboratories (departments)
    - extend response in cross-disciplinary research areas
- To add possibilities for generating new business in the areas of life cycle testing and life cycle simulation. This means:
    - new methods in life cycle estimation
    - extend response in cross-disciplinary research areas

SEPARATE EXPECTED RESULTS – INDUSTRIAL CASES

The project is divided to four research work packages or sub-projects and industrial test cases. The sub- projects are defined according to the research needs of the industry. Work packages are:

WP1: Predict malfunctions by testing
WP2: Accelerated component testing
WP3: Adaptive life cycle estimation
WP4: Failure and ageing mechanisms and models

Every WP contains one research application Case. As output of these Cases are expected following results:

- Test procedures for accelerated testing of selected components in their real operation environment.
- Procedure to generate accelerated test data for physical and simulated life time testing based on field data.
- Model for adaptive life cycle estimation of selected components.
- Model of the influence of cavitation on the wear of impeller blades.
- To collect failure and ageing mechanism collection of selected components.

RESEARCH ENVIRONMENT

The project is a co-operation of four laboratories of Tampere University of Technology (Materials Science, Intelligent Hydraulics and Automation, Mechanical Engineering and Industrial Systems and Electrical Engineering) and two foreign universities (University de Grenoble, Laboratoire des Ecoulements Géophysiques et Industriels (LEGI) and University of Maryland, USA).

Project is financed by Tekes and industrial companies Sandvik Mining and Constructions Oy, Valtra Oy Ab, Fortum Power and Heat Oy and Teollisuuden Voima Oyj and Tampere University of Technology. Companies Neurovision Oy and Distence Oy bring knowledge and other support in to the project. Project manager is docent Juha Miettinen (Materials Science) and director in charge is professor Pentti Saarenrinne. Time span is from 1.8.2014 until 31.7.2017.

PUBLICATIONS UNTIL NOW

Simulointi nopeuttaa käyttöiän määritystä. Promaint magazine 2/2015

Kehitysyhteistyötä. Koneviesti magazine 4/2016

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Miettinen, J., Saarenrinne, P., Kokko, V., Hasanen, M., Ylönen, M., Ojala, P. Hydraulic Machines and Cavitation. 3-4.6.2015 Nantes, France. Societe Hydrotechnique de France (SHF) conference. SHF Workshop: Hydraulic Machinery, Cavitation.

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4. ADVANCED FAULT TREE ANALYSIS FOR LIFE-CYCLE COST BASED DESIGN

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ABSTRACT

Over 50 years old traditional fault tree analysis (FTA) can be applied to a large variety of complex risk assessment cases but for example modelling of operation or phase changes of the systems, stochasticity and delays of the relations, and maintenance actions of the components cannot be included. This paper presents the advanced FTA method which extends the traditional FTA also for dynamic systems with time dependent activities. Failures, operation profiles, preventive maintenance and all other details that affect the life-cycle cost (LCC) of the system can be included in the comprehensive model and different scenarios can be compared already at the design stage. Stochastic discrete event simulation (DES) is used to create versatile concrete results that utilize all the information combined to the model. To allow best possible freedom for tailoring needs, special rules between failures and other simulated properties can be defined by including Java based scripts in the model.

INTRODUCTION

It is very beneficial, or even mandatory, to be able to verify the quality and evaluate the risks of the system. Risk is expressed in terms of a combination of the consequences of an event and the associated likelihood of occurrence. (ISO GUIDE 73, 2009) Reliability, availability, maintainability and safety (RAMS) are system quality attributes (IEC 60050-191, 1990) that are used for explicit understanding of likelihoods of risk related events. The consequences of dependability related events are for example break, downtime, corrective maintenance (CM) and preventive maintenance (PM) costs. Also safety related events, called hazards, can exist with potential harms, such as injuries or damages to the health of people, or damage to property or the environment. (ISO GUIDE 51, 2014) These essential factors related to risk are illustrated in Figure 1. Understanding of these factors is needed for making rational decisions on how to improve the system most efficiently.

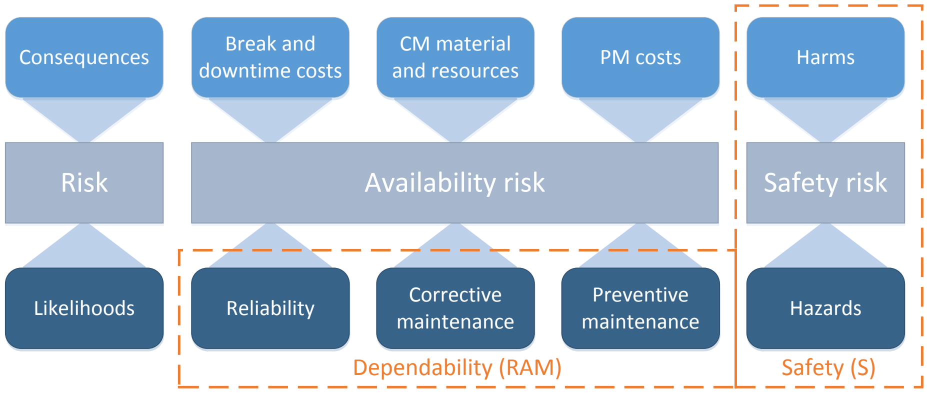

Figure 1. The essential system quality factors related to risk

At design phase the alternatives can be compared by creating and analysing a model that describes the features of the system under design. For already existing systems it is possible through modelling to predict the overall effect of proposed modifications. Without any major modifications and investments the maintenance optimization can be used to improve the performance of the current system. In each of the previous situations all the knowledge must be collected, combined and analysed to obtain the ideal solution.

The comprehensive RAMS model is a sophisticated way to store all the useful information. Figure 2 illustrates how the RAMS model, technical performance and design requirements can affect each other and form the information for the system design and development. When all the details and their connections are known it is possible to compare different scenarios and design alternatives for example from the estimated life-cycle costs (LCC) point of view. Stochastic discrete event simulation is used to produce detailed, concrete and explicit results.

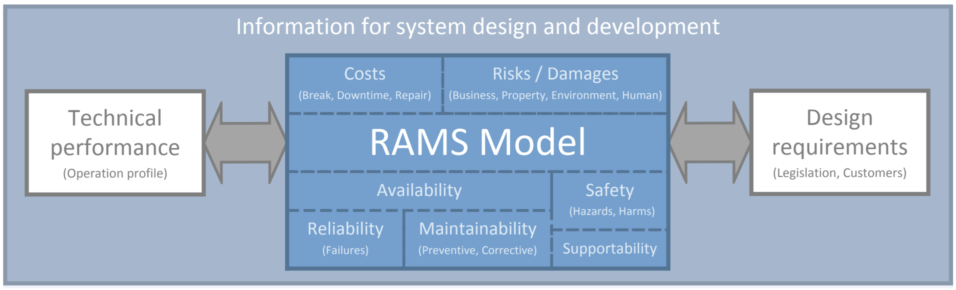

Figure 2. RAMS model is an integral part of the system information that allow to estimate LCC

ADVANCED FAULT TREE ANALYSIS METHOD

The advanced FTA model structure stores detailed information about causes and consequences of potential failures. (Virtanen et al., 2006) The model consists of nodes and relations. Relations have a freedom to be connected to any number of source and target nodes, which makes the structure similar with directed hypergraphs. (Ruohonen, 2013) Universal model allows inclusion of various standard risk assessment methods. (EN 31010, 2010) It is possible to combine several commonly used techniques into a comprehensive RAMS model as illustrated in Figure 3.

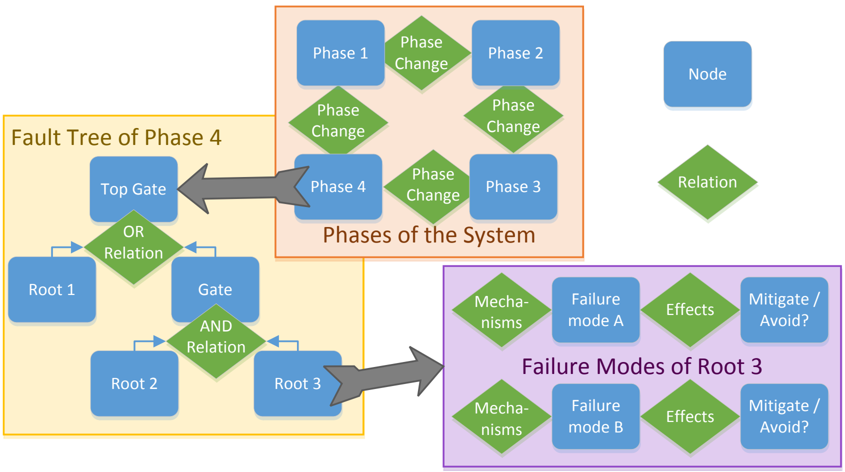

Figure 3. Comprehensive RAMS model that consists of three levels with different techniques

The method allows straightforward modelling of dynamic operation rules of the system. Simple situations that require dynamic rules are for example pausing of all non-failed components during a system failure, cold redundancy, operation phases and preventive maintenance actions. Because there is wide diversity of such needs, the advanced FTA method allows free definition of dynamic rules for expert users and easy to use collection of simple dynamic rules for basic users. Java based scripts are used to define for example how and when source nodes of relations affect target nodes and which node variables are updated in which situation during the simulation process. This approach called template method pattern allows to include free tailoring whenever customization of the simulation algorithm is required for efficient analysis.

The feasibility of the approach is verified for example with particle accelerators. Tailoring is required to study integrated luminosity similarly with LCC as a result value. This key performance indicator requires a definition of overall production function which combines availabilities of different parts of the accelerator complex, operation/maintenance strategy, maximum luminosity production and other details. (Apollonio, 2015) The dynamic production is modelled by using Java based scripts to create a semi-Markov process for the operation phases. The failures are modelled with fault trees with dynamic rules for operation phase based changes of failure modes, rates, and effects. This complexity together with large-scale infrastructure needs the features that advanced FTA approach adds to traditional risk assessment methods.

CONCLUSIONS

Advanced FTA allows to combine the most common standard risk assessment techniques and also to define tailored features based on special needs. Universal model makes it possible to collect all the expert knowledge together with possibly available big data. This allows to include all the known details that affect for example the LCC of the system under design. Single method that is applicable for a large variety of systems and cases allows to invest more for creation of tool that with sophisticated graphical user interface (GUI) and application programming interface (API) makes the use of the method as straightforward as possible. The method, the tool and the interfaces are designed to be as easy to adapt as possible, but still so general that they are never a reason to make a compromise. It should be beneficial to apply this sophisticated approach always when the information and all details required for the justified decision making related to system quality and risks are no longer possible to be handled by a person himself.

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5. STATISTICAL RELIABILITY PERFORMANCE OF ROLLING-ELEMENT BEARINGS IN WIND TURBINE GEARBOX

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ABSTRACT

This paper is a literature survey, concerning the statistical reliability performance of rolling-element bearings in wind turbine gearbox. In this study we did examine the predictability of the bearing failure in wind turbine gearbox compared to the test conditions. The finding of this study was that the timing of failures of sample of bearings in wind turbine gearbox is more predictable than the timing of failures of sample of bearing in laboratory test conditions. Also it was discovered that the failure rate (hazard) growth for sample of bearings in wind turbine gearboxes is accelerating, whereas for sample of bearings of test conditions is decelerating. Also some comparison was done with journal bearings in test condition. The sample failure behaviour of journal bearings was found out to be the most unpredictable.

INTRODUCTION

The need of understanding the reliability of bearing in gear box of wind turbine is well justified since the failure of bearing is usually the main cause of the whole wind turbine gearbox failure (2, 3, 5, 6, 11). On the other hand Robb D et al. (8) stated that bearing failure generally starts the gearbox failure. Furthermore since the gearbox failures causes longest down times per failure compared to other subsystems of the wind turbine (4, 11, 13) it is clear that the reliability of the bearing in gearbox is important when considering the reliability of the whole wind turbine.

The failure behavior of set of bearings (especially for rolling-element bearings) typically follows the Weibull distribution function (17, 18). For this reason the search for parameters of Weibull distribution function from the field data of wind turbines have been selected as a main target of this study. The Weibull parameters are generated by fitting Weibull curve on the recorded historical failure data from the field.

THEORY

Failure distribution: The two parameter Weibull distribution function can be expressed as:

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}}$$

where t is time ($t > 0$), η is the *scale parameter* and β is the *shape parameter* (30). Failure distribution F(t) ($\in [0,1]$) describes the rate of failed samples out of the whole population at the moment t. Thus F(t) = 0 indicates no failures and F(t) = 1 indicates that the whole population is failed.

Failure rate for Weibull distribution is

$z(t) = \frac{f(t)}{R(t)} = \beta \left(\frac{1}{\eta}\right)^{\beta} t^{\beta-1}$ for all $t > 0$

The first order time derivative of failure rate is

$$z'(t) = \beta \left(\frac{1}{\eta}\right)^{\beta} t^{\beta-2}(\beta - 1)$$

RESULTS

Cumulative failure behaviours of bearings in wind turbine gearbox from different sources are plotted in Figure 1. From the figure it can be seen that failure behaviour of high speed shaft bearing (HSS) is less unpredictable than the intermediary speed shaft bearing (IMS). In case of IMS bearing we can conclude that the bearing is somewhat reliable during the first 7 years and after that starts the wear out period. The wear out period lasts next 9 years after which only 10% of the population is still functional. Similar trend can be seen form Poore R et al. and Martin-Tretton M et al. plots with the exception that the durability is better. In Van Bussel GJW et al. case the failure rate is independent of time leading to exponential cumulative failure behaviour.

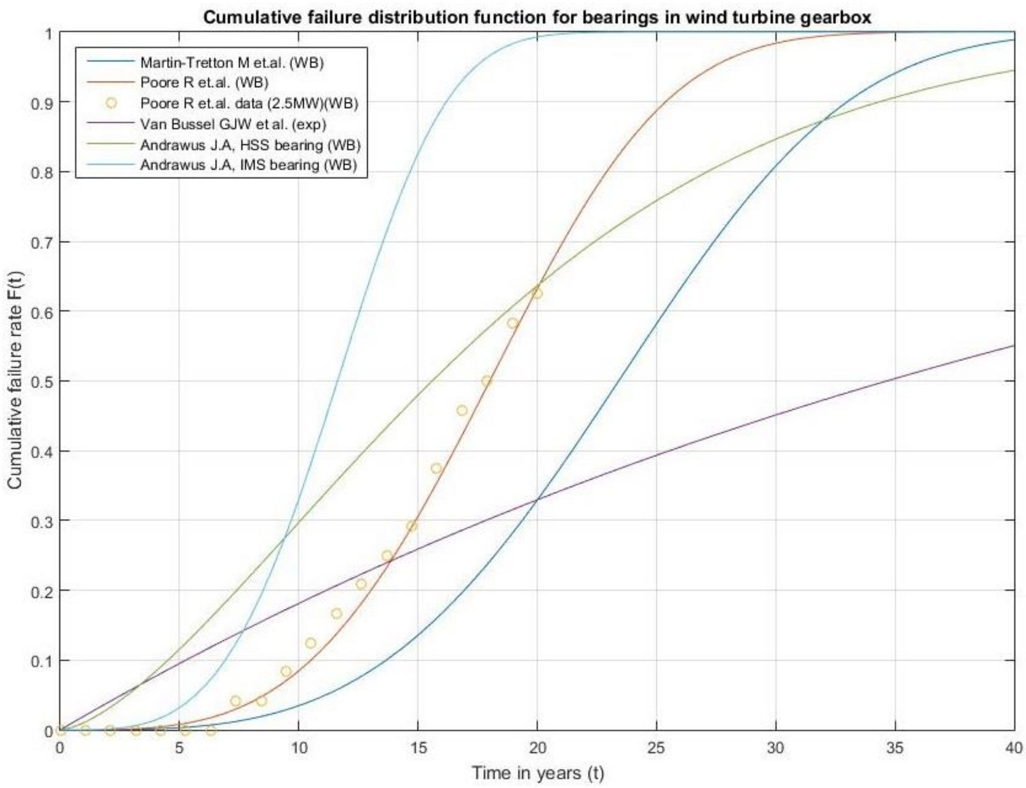

Figure 1: Time dependent cumulative failure behaviour of rolling-element bearings in wind turbine gearbox, suggested by several studies.

The suggested values for Weibull shape parameter for rolling-element bearings in wind turbine gearbox were between 1.52 and 3.63. In test conditions the parameter for rolling bearings is average 1.51, by having the 50% interval between 1.17 and 1.74 (24). For journal bearing in test condition the Weibull shape parameter is between 0.86 and 1.48 (27). The results are illustrated in Figure 2.

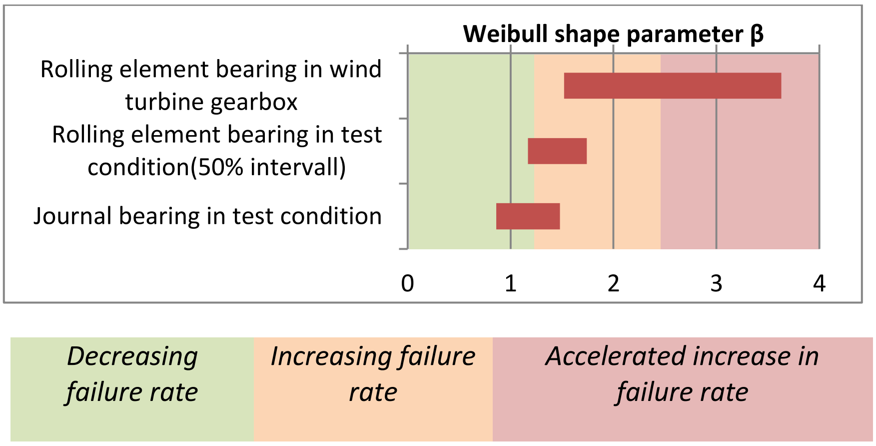

Figure 2: Value range of Weibull shape parameter for bearing of different types and different operation conditions.

CONCLUSION

None of the references of this study suggested Weibull shape parameter to be under 1 for bearing in wind turbine gearbox. Instead in Lieblein & Zelen (24) survey 11% of rolling element bearings had Weibull shape parameter smaller than 1. Shape parameter smaller than 1 indicates decreasing failure rate with time. This could be interpreted that the surviving population is getting more and more reliable during the time. This phenomenon seems not to be involved in bearings of the wind turbine gearbox at all.

The bearings of wind turbine gearbox HSS have Weibull shape parameter in range of $1<\beta<2$. Weibull shape parameter in range of 1 and 2 indicates increasing failure rate but the trend is decelerating with time. In Lieblein & Zelen (24) survey total 76% of test groups had this characteristic. Thus this seems to be major trend with rolling-element bearings in test conditions, but not in wind turbine gearboxes.

Rolling-element bearing in wind turbine gearbox seems to have Weibull shape parameter greater than 2. This indicates accelerating trend in failure rate growth with time. This kind of trend could be interpreted as an accelerated wear out. This trend is not significantly in involved in rolling-element bearings of the test conditions since only 13% of test groups in Lieblein & Zelen (24) survey had shape parameter greater than 2 and only 1% had the shape parameter greater than 3.5.

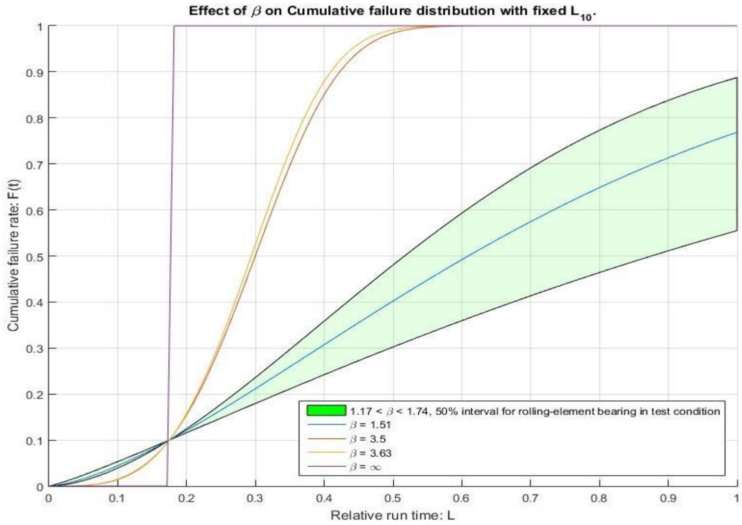

Figure 3: The illustration of the effect of Weibull slope parameter β on cumulative failure rate F(t) when $L_{10}$is fixed.

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6. OPERATING CONDITION FORECAST BASED OPTIMIZATION OF INDUSTRIAL SERVICE DELIVERY

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ABSTRACT

A prediction of the operating conditions of a machine is created by using a data from IoT measurements and environment and process data sources. A machine learning system is then used to predict the future rates of change of performance indicator values, such as degradation, energy consumption and output rate, based on the predicted operating conditions. After obtaining these predictions, agent based methods can be used to manipulate changes in the input parameters of the machine learning system in order to optimize the indicator values, to explore what kinds of changes in the operational conditions of the machine would maximize its performance. The discovered parameter changes can then be compared to the available industrial services in order to create service combinations that would optimize the productivity of the machine, or a machine system. It is also possible to detect emergent service potentials that are not covered by existing services. As the concept is to create abstractions of measurement data and compare those to find the optimal situation, it is easily applicable to a variety of machine systems and scalable up to fleet level. A fleet level model would also enable the optimization of limited service delivery capacity.

INTRODUCTION

Operating conditions as a whole determine the performance of a machine. These operating conditions, including manufacturing schedule, process variables, operator skill level, ambient temperature and air humidity affect the operational efficiency and remaining useful life of a machine. Industrial services can be seen as actions manipulating these operating conditions in order to optimize the operational efficiency of the machine.

Industrial internet measurements and external data sources make available more and more measurement data concerning the operating conditions of a machine. Current machine learning methods, especially neural networks, are good at learning patterns in data and creating predictive models based on these patterns (Gers 2001). It is possible to use the available data to teach the neural network models the connections between the changes in operating conditions and the changes in the operational efficiency of a machine.

Creating predictions of the operating conditions would then enable the corresponding predictions of operational efficiency. By manipulating the operating condition prediction and observing the changes in the operational efficiency prediction the correct industrial service needs in the predicted future conditions could be found. This means optimizing several variables which are all affected by the same set of inputs, which can be done using the Multi Agent System modeling paradigm (Weiss 2013).

These technologies enable the dynamic identification of industrial service potentials as well as identification of emergent service potentials in the predicted operating conditions. The use of machine learning and intelligent agents also enable flexible expansion of the proposed modeling methodology to a fleet level. A fleet of machines and related services can be classified as a

System of Systems (Rainey 2015), which indicates the presence of evolution and emergence in the system, further requiring adaptable modeling strategies.

MODEL CONCEPT

The process of optimizing services begins with creating a prediction of future operating conditions. A time series forecast of the changes in the operating conditions of the machine is created. These changes are then mapped to the changes of performance indicator values, which represent the measurable operational efficiency and remaining useful life metrics of the machine. Then, by manipulating the operation condition prediction and examining the corresponding behavior of the performance indicator values, the long term operational efficiency of the machine can be optimized. The gained optimization solutions represent the needed changes in the operating conditions of the machine. These changes can be effected by industrial services and with this information it is possible to create a service package that optimizes the use of the machine under the predicted operating conditions. It is also possible to identify new service potentials, should there be suggested operation condition changes that are not dealt with by existing services. The process has three distinct phases, creating the prediction, optimizing the conditions and choosing the services. These are shown in figure 1.

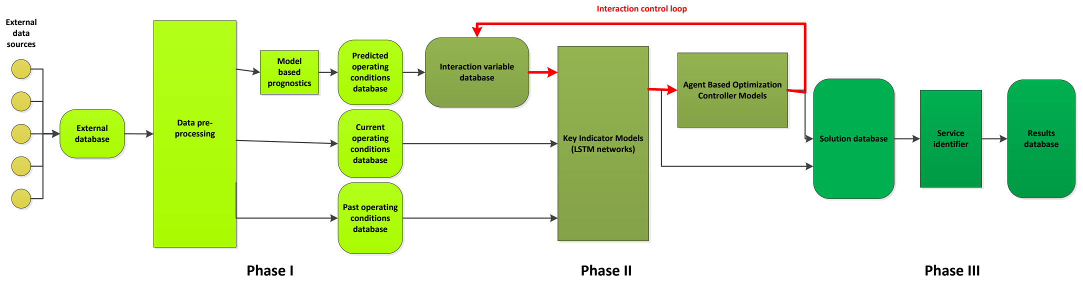

Figure 1: Model structure concept

In phase 1, data is collected from sources such as databases of weather, markets and energy as well as process data such as planned production schedules and machine operator work shifts. After the data has been acquired, it is pre-processed to create the operating conditions predictions. Some of the data already contains forecasts and plans, while some requires predictions to be made using history data and trained machine learning systems, or other methods of model based predicting. When the data collecting and pre-processing is complete, a time series prediction of the future changes in the operating conditions of a machine is obtained.

In phase 2, the predicted operating condition variables are inputs for neural networks predicting the performance indicator values. Any changes in the operating conditions affect all of the indicator values, so while every indicator has its own model, they all have the same set of input variables. The output of the neural networks is a time series prediction of the performance of the machine under the predicted operating conditions. This approach models the actual situation the machine is operating in in the future.

Once the prediction of the performance of the machine is obtained, the performance indicators are optimized. For this complex optimization problem, an agent based model is used. A controller agent is created for each of the performance indicator models. The agents manipulate the operating conditions prediction as they attempt to optimize their respective performance indicator results. They also have the ability to negotiate with each other in order to find a set of operating condition changes that give the best overall behavior of the performance indicators.

In phase 3, once enough acceptable sets of operating condition variable manipulations and their effects on the performance indicators have been collected, the optimization loop is cut. The results are compared to available industrial services in order to discover what types of service combinations would optimize the efficiency of the machine. New service potentials can also be discovered.

CONCLUSIONS

Once this concept model is developed further in industry cases, we expect to have a proof of concept of a modeling methodology that has the capability to aid dynamic service delivery based on IoT-data. The methodology is scalable from a single component level to a fleet of machines and able to adapt in the evolving system of systems it is intended to be used in. By the correct choice of parameters, it is expected to work in different types of machines or processes, as it is not dependent of the actual structure of the modeling target, only on the availability of data and knowledge of the important interactions and desired performance characteristics of the target. Important research questions include listing the knowledge required for the modeling, constructing and training the neural networks to enable the predictions needed, the amount of data needed in their training, the exact structure of the multi agent system model as well as the methodology of identifying the service potentials based on the simulation results.

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7. AUGMENTED REALITY BASED CONTEXTUAL SOCIAL MEDIA IN INDUSTRIAL ENVIRONMENT

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ABSTRACT

Contextual social media is a concept where users can embed media files into physical objects and the environment. This facilitates sharing text, video and audio related to the physical object in question. We have studied how the concept could support sharing tacit knowledge between maintenance personnel in industrial contexts. In our Augmented Reality (AR) based implementation, target objects are recognized with a smart phone based on the object's visual appearance. The visual appearance is further associated with a unique hashtag. This makes it possible to attach social media messages to that particular object just by including the appropriate hashtag to that message. When a service technician views the maintenance target with a smart phone, he can automatically see the attached posts from colleagues globally, or add new posts, for that particular machine. The hashtag can also connect the messages more widely, e.g. to a certain type of machine. Initial user feedback has been very encouraging and maintenance professionals saw that contextual social media could network maintenance technicians in a natural way, and could even replace separate networking applications that have been challenging to adopt at work places.

INTRODUCTION

Industrial internet and service business have potential for radical improvements in industrial field maintenance services regarding service quality, work satisfaction, productivity and risk reduction. In the Finnish national DIMECC S-STEP program we have developed Augmented Reality based concepts of knowledge sharing solutions for mobile field service personnel. A particular goal of the project has been to develop fluent methods for gathering and sharing tacit knowledge during the maintenance work. Tacit or implicit knowledge, not easily accessible in any stored format but just in the workers' experience, is often counted to be more than 80% of all information available.

Organisations 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 where media files are embedded in everyday objects and the environment. This facilitates easy access and storage of, e.g. text, video and audio related to the physical object in question (Kaasinen et al., 2010). Contextual social media is characterised by:

- 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

In our interviews with maintenance technicians, user initiated knowledge sharing was oftendescribed. The technicians for instance described how they often write down notes for the nextmaintenance visit e.g. on the cover of the machine to be repaired. The notes may indicate specialconditions 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 him/herself for the next visit as well as his/her colleagues.

These interviews encouraged us to try out a completely new approach for collecting tacit knowledge among maintenance workers, Augmented Reality Social Media (AR SoMe). The AR SoMe application bears a strong resemblance to physical post-its and notes, however at the same time providing a direct link to digital reporting and information sharing systems. Similar augmented SoMe applications have previously been introduced in research (e.g. Langlotz et al., 2012) and also commercially in the consumer domain, e.g. WikiTude (city info, points-of-interest) and Tagxy (consumer goods), but not in industrial context.

The user feedback to the AR SoMe concept has been very encouraging, even if the evaluations by now are only based on concept descriptions. In the following we describe VTT's AR SoMe solution that will be piloted in DIMECC S-STEP program. We then describe the initial feedback from maintenance personnel based on a focus group where AR SoMe and many other knowledge sharing solution concepts were assessed by maintenance professionals.

AR SOME SOLUTION

The AR SoMe technical implementation is based ALVAR, a 3D tracking SDK developed by VTT; see http://virtual.vtt.fi/virtual/proj2/multimedia/alvar/mobile/index.html. Among other features, ALVAR can be used to recognize target objects based on one or more reference images. The reference images can also be used for tracking the camera's position so that it is possible to augment virtual content to the target object in the live video view, e.g. on camera phone or tablet.

The AR SoMe application assigns each target object a unique hashtag (e.g. #AR5673fd12c2095). New target objects can be created simply by taking one or more reference images of the target. When the same object is viewed again, the software recognizes it by comparing the visual appearance to the reference frames and returns the associated hashtag. Social media messages are attached to an object by including the detected hashtag to the message. When viewing the target object with the AR SoMe application, the user automatically sees the attached posts and can add new posts to the object. The messages can be browsed in AR view , or searched without video view using more traditional text interface.

AR SoMe can use traditional social media sites like Twitter of Facebook, but it works just as well for any messaging platform, including chat rooms that are internal for the company. The messages can be categorized and moderated on the server, e.g. automatically created hashtags be given more meaningful names, and the material can be collected to further handbooks etc.

The hashtags may connect the content to just a specific maintenance target or a machine type, or they can be utilised to follow globally the tacit knowledge that is gradually been gathered.

Figure 1. Concept image: accessing contextual social media in a maintenance task by means of object detection and Augmented Reality.

USER FEEDBACK

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 long work history in different maintenance positions, and three of them were currently in managerial positions.

We presented the AR SoMe concept to the participants with a video that illustrated using AR SoMe in office environment; see https://youtu.be/-soabHbUzwM. Even if the environment was different from an industrial one, the participants easily understood the concept and could imagine using it in maintenance context.

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 at

work place:

- ”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 on the brakes that these settings work well in here, and anothertechnician could see the advice augmented on similar set of brakes right away”

The professionals saw that the AR SoMe concept would facilitate getting actual feedback from thefield. Currently the feedback is unconnected, AR SoMe could facilitate integrated information and connecting 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 inform who should be informed about the message, e.g., #safety or #quality. In this way the message could reach also 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 wrong advice. However, they thought that the network will help in assessing the information:

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

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

- ”What if I do not notice the AR 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?”

CONCLUSIONS

The overall objective for Konecranes in the DIMECC S-STEP research program has been to improve service visits' efficiency by identifying equipment and system with the help of Augmented Reality. We have identified content production as one of the main challenges in AR based maintenance support. AR SoMe provides a promising platform and process for creating AR content and turning technicians from content consumers into content creators.

Real-time tracking provides means to study the benefits of contextual information and support for technicians to carry out their tasks. Service technicians welcome technology and new solutions that make their work easier and more effective. Easier and more focused reporting is a welcome goal for them as well.

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II Additive Manufacturing

8. CHALLENGES AND SUCCESS FACTORS IN CREATING RADICAL MANUFACTURING TECHNOLOGY INNOVATIONS

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ABSTRACT

Radical Manufacturing Technology Innovations (RMTI) renew the technology equipment that a manufacturing firm uses in its core production process and transform the process in a significant way. Previous research does not cover the manufacturing firms' perspective to succeeding in the creation of RMTI. The goal of this study is to identify key challenges and success factors in RMTI creation. A qualitative study was conducted with manufacturing firms located in Finland, whereby 23 different exemplary cases of RMTI were explored. Success factors are revealed in supplier firm competence, expert resourcing, good pre-planning and early feedback, and coordination.

BACKGROUND

Radical manufacturing technology innovations (RMTI) typically involve a switch in the technology used in the firm's core production process. Capability for creating RMTI is important for manufacturing firms, especially when they are seeking new directions for growth. Renewal of production capability, new product development and new business development may demand the creation and adoption of new-to-firm production equipment and processes.

Previous research on RMTI perceives the creation and adoption of RMTI as separate processes occurring in different contexts: the manufacturing firm is seen mainly as a buyer of the equipment, and the equipment supplier firm is seen as the innovator for industrial equipment (Damanpour and Wischnevsky, 2006). Studies on the success of technology adoption have covered the factors influencing the successful implementation of new technology equipment, achieving enhanced production performance and the full potential of the new technology equipment (Swink & Nair 2007, Da Rosa Cardoso et al. 2012, Stock & Tatikonda 2008, Karlsson et al. 2010, Khazanchi et al. 2007). These earlier studies, however, do not cover if and how the adopting organization is involved during RMTI creation. Collaborative relations between the technology supplier and the manufacturing firms have been considered as a key success factor for RMTI creation (e.g. Rönnberg-Sjödin 2013, Dulluri and Raghavan 2008, Terweisch et al. 2005). The goal of this study is to increase understanding on the creation of RMTI, particularly from the manufacturing firm's perspective. The main research question is: what are the key challenges and success factors in the creation phase of RMTI.

RESEARCH METHOD

We employed a qualitative, exploratory research design to study various RMTI cases in Finnish manufacturing firms. A wide variety of cases (n=23) from different contexts (e.g. firm size, industry, technology) were studied. The manufacturing firm perspective was dominant, but a few equipment supplier firms were also included. Semi-structured interviews were carried out with individuals closely involved in the RMTI, with the RMTI cases as the unit of analysis. All main phases of RMTI were covered in the interviews: initiation, adoption decision, creation and implementation. This paper focuses on the success factors and challenges in the 'creation' phase. The data were content analyzed through an inductive approach, looking at both the specific case and its contextual setting.

FINDINGS

The studied RMTI cases all could be considered successful in the sense that they had resulted in technologies and processes that were in use by the manufacturing firms. Supplier's previous experience and expertise, the manufacturing firm's own or another partner's technical expertise, good pre-planning and early technical feedback, and good coordination routines were considered as key factors in the success of RMTI creation (including design and development). The interviewees experienced that the creation of RMTI was challenged due to its inherent novelty (i.e. there was no or only a little previous experience about similar kinds of innovations) and various technical and market uncertainties (i.e. there was no evidence of the technology in use before, and no knowledge of how attractive the innovation would be on the market). Table 1 summarizes the findings regarding success factors and challenges. A positive decision in the manufacturing firm to invest in the RMTI creation was seen as a key milestone. 'Right individuals' were perceived to be among critical success factors in RMTI creation, highlighting the role of technical experts, interested individuals as dedicated resource in the various phases of development, whether in the manufacturing firm, the supplier firm, or another partner organization.

	Description
Success Factors	
Supplier's expertise	• Smooth design and construction of the equipment. • Good project management. • Previous similar experiences and related competence.
Own or partner's technical experts	• The involvement of technical experts in the manufacturing firm, a subcontractor firm, other partner organizations, or researchers (particularly with high degrees of technology novelty in the supplier firm). • Access to their experience and competence. • Good ideas in design and construction.
Good pre-planning and early feedback	• Creating prototypes, and gaining early feedback on technical issues. • Sufficient time for good pre-planning in the early phase. • Allocation of sufficient resources to the RMTI projects, particularly in high-novelty technologies.
Coordination	• Coordination within the supplier firm, within its network of subcontractors and with the manufacturing firm. • Clear requirements and specifications at the early phase of RMTI creation.
Challenges	
Lack of experience and expertise in the supplier firm	• Lack of technology-specific, construction-specific and project management competences. • The need to try, rework and learn during the RMTI project.
Uncertainty in design and development	• Finalizing the technology specifications and committing to them early enough. • Managing changes in the product design later on.

Table 1: Success Factors and challenges in the creation of RMTI.

CONCLUSION

While the creation of RMTI has earlier been studied mainly from the equipment supplier firms' perspective, this study highlights the manufacturing firm as an active contributor in RMTI creation. Lack of experience (novelty) and lack of technical details about the equipment construction (uncertainty) were experienced as key challenges in RMTI creation, and they create various demands for the suppliers' competence in planning, designing and testing the RMTI and project management. The manufacturing firm needs insight about the RMTI creation process, to be able to use the technology supplier's competence effectively. Supplier organization capabilities and a close collaborative relation with manufacturing firms have been considered as key success factors in the creation of production equipment innovations, and the results confirmed this. Our findings point out the need for access to technical expertise in the manufacturing firm and other partner organizations, particularly in cases of high technology novelty at level of the supplier firm. Good pre-planning and access to early feedback, such as through building prototypes, and additional resources were among key success factors in RMTI creation. A positive decision to invest in RMTI from the manufacturing firm is a critical turning point, enabling the creation process. The findings show that RMTI creation is a networked effort, requiring smooth interactions and project management.

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9. TOWARD DEVELOPING SURROGATE MODEL INTEGRATING MULTI-PHYSICS, MULTI-CRITERIA MODELS FOR ADDITIVE MANUFACTURING TECHNOLOGIES

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ABSTRACT

Additive Manufacturing (AM) is intensifying the digitalization of the manufacturing and generating disruptive changes and the paradigm shift in the industry. To boost the productivity in AM, the improvement in parts qualification is required. Qualifying the parts implies the capability to ensure constant and repeatable part properties meeting the engineering design requirements. It implies to certify not only the structure, properties and global performance of a part but also its manufacturing process. Modelling and simulation techniques can target them separately, but linking models describing those characteristics is quite challenging since they have the different level of details and sometimes different purposes. Presenting those models in the form of causal graph will enable us to combine models with different level of details. The current research utilizes functional analysis and dimensional analysis to present the models in the form of the causal graph between associated parameters. The DACM Framework integrating fundamental required methods and theories is briefly explained in this article. The current research will then aim at developing a surrogate model capable of integrating the different models such as microstructure models, layer by layer melting/solidification and part models. The final comprehensive model can simulate to AM system to fulfill multi-criteria performances.

INTRODUCTION

Integration of Additive Manufacturing into the existing manufacturing technologies and boost the productivity in AM requires a reliable part qualification. Therefore, a deep understanding of different AM processes, their capabilities, and limitations, their associated multi-physics, can guide the manufacturing sector to be able to certify the additively manufactured parts. To provide the required knowledge for each process with less amount of time and expense, the modelling and simulation play a significant role. Despite the existing modelling challenges such as the multiphysics nature of processes, the current models and simulations offer the relatively higher maturity, due to the advancement of information technology and computational science. Each model is developed with different purposes, different level of detail, and different constraint. Even though developing mature models are crucial, those models usually often cannot be reused by switching from machine to machine or from process to process. Furthermore, different models with different purposes and level of detail can be seen as the separate islands that are not integrated toward a worthwhile multi-criteria model. So the research question rises up here is 'how to link different models with different purposes and details, for having a holistic multi-criteria model in AM?'. Toward this end, Witherell et al. from National Institute of Standard and Technology (NIST) proposed to use a metamodeling approach and develop the ontology for supporting the model reusability [1]. To tackle this research question, we believe that presenting the models in the form of the causal graph will enable us to combine models with different level of details and different purposes. Different models such as microstructure models, layer by layer melting/solidification and part models for each AM process can be integrated into a surrogate model. So the fundamental goal of the research is to use the network-based approach to present a causal model that can be simulated. In order to achieve this aim, we are applying Dimensional Analysis Conceptual Modelling (DACM) Framework on different additive manufacturing technologies such as Direct Energy Deposition (DED) [2], Fused Deposition Modelling (FDM) and Cold Metal Transfer (CMT). The fundamental pillars of DACM Framework are briefly explained in the methodology section.

METHODOLOGY

Dimensional Analysis Conceptual Modelling (DACM) Framework is a powerful modelling methodology, initially developed for specifying, discovering, validating and analyzing system behavior [3]. The methods and theories integrated into the framework are articulated around fundamental pillars such as functional modeling, dimensional analysis, Bond graph organs, causal rules and colored hypergraph. Figure 1 illustrates the step by step modelling procedure using DACM Framework. After clarifying the model objective and defining system borders, the modeling starts with functional modeling of an existing system or a system to be designed. Presenting proper functional architecture is mostly important because a reliable modeling or simulation highly depends on upon a solid knowledge of the sequence of functions taking place in the system under investigation. Then the functional model of the system will be mapped to the Bond Graph representation of the system. This mapping is done for each function based on the vocabulary mapping presented by Hirtz et al. [4]. The Bond graph is a type of domain independent graphical representation of a system. The Bond graph is composed of limited 'elements' which are linked together by the 'bonds' [5]. The idea of mapping the functional model to the bond graph is first because of being able to multi-domain and multi-physics model, and second for the reason of using causality rules in the theory. In the next step, the influencing variables of the system are assigned to the latest bond graph representation. Based on the causality rules and assigned variable, we are able to present a special neural network, in which the variables are connected to each other based on their causality. So at the end of step 6 (See Figure 1) the models are presenting in the form of the causal graphs to describe the physical phenomenon of the model. This causal graph is then transferred to the colored hypergraph.

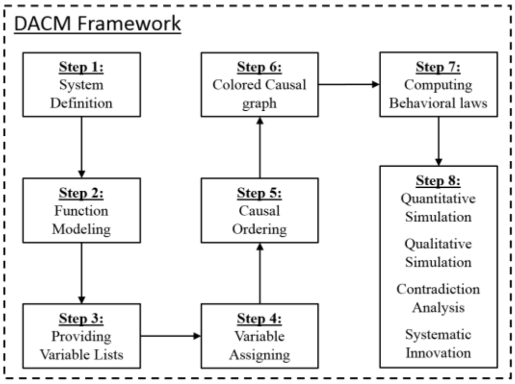

Figure 1 Modelling steps of DACM Framework

Afterward, based on the casual graph and the unit of each of variables, we are able to compute the behavioral laws of the system under investigation using dimensional analysis. Dimensional Analysis has been developed to deduce the mathematical relation between variables from the fundamental dimensions of variable (Mass, Length, Time, etc.) [6]. The eager readers are invited to find more detail information about the DACM framework in the article published by Eric Coatanéa et al. [7]. The models in the form of causal graph adding to their behavioral laws can be combined to each other. Then can be used for different kind of purposes such as quantitative simulation, contradiction analysis, qualitative simulations or as a systematic approach toward innovation.

CONCLUSION AND PERSPECTIVE

In this paper, the fundamental objectives of the current research and general description of the methodology were briefly explained. We are aiming at developing the method for presenting surrogate model capable of integrating the models with different purposes and level of detail that can be simulated. Having this kind of model will help us to increase the predictability and reliability of AM to boost the productivity of this emerging technology. One of our future research will be dedicated to the in-situ enrichment the network based model using the sensor on the additive manufacturing device and consequently act online on the parameter setting in order to reach the desired performance.

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10. NEW DESIGN APPROACHES FOR ADDITIVE MANUFACTURING

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ABSTRACT

Additive manufacturing (AM) enables the manufacture of nearly any geometry without the constraints imposed by traditional manufacturing techniques. As this technology advances and the costs of 3D printed parts continue to fall, AM will become a more prevalent and viable engineering and business solution. In order to take full advantage of this technology, new approaches to design need to be adopted to incorporate the geometric freedom offered by AM for the creation of functionally superior and cost-effective solutions. VTT has been investigating several new simulation and design approaches, including the use of topology and lattice optimization techniques, 3D printing of sandcast molds for cast metal components, and the creation and use of design guidelines for parts produced by selective laser melting process. This paper will provide a brief overview of this ongoing work and the potential benefits of each approach.

INTRODUCTION

The creation of components in a layer-wise fashion, which is typical in additive manufacturing (AM), enables the fabrication of nearly any complex shape. When compared to traditional manufacturing techniques, this newfound design freedom can be used to create components that are complex, lightweight, consolidate several parts into one, eliminate the need for assemblage, customizable, and functionally superior [1]. In order to take full advantage of the tremendous potential offered by AM, it is not enough to simply start printing existing components that can be manufactured by more traditional techniques. Components should be designed (or redesigned) specifically for the AM process that will be used.

CREATION & USE OF DESIGN GUIDELINES FOR SELECTIVE LASER MELTING

While AM promises much greater design freedom than traditional manufacturing methods, there are still limitation, which vary with the given AM process. Understanding these limitations is paramount for designing a component that meets the initial design criteria, can be printed, and can be post-processed (including anchor and support removal, heat treatment, surface treatment, machining, etc.) in a cost-effective manner. For this purpose, a study was conducted to establish design guidelines for the selective laser melting (SLM) process. Figure 1 describes some of the test geometries that were utilized to investigate various design features. The test series were printed in AlSi12, Inconel, tool steel H13 and stainless steel AISI 316L using a SLM125HL printer. The parts were examined, and the findings were summarized as design rules for metal SLM component design [2].

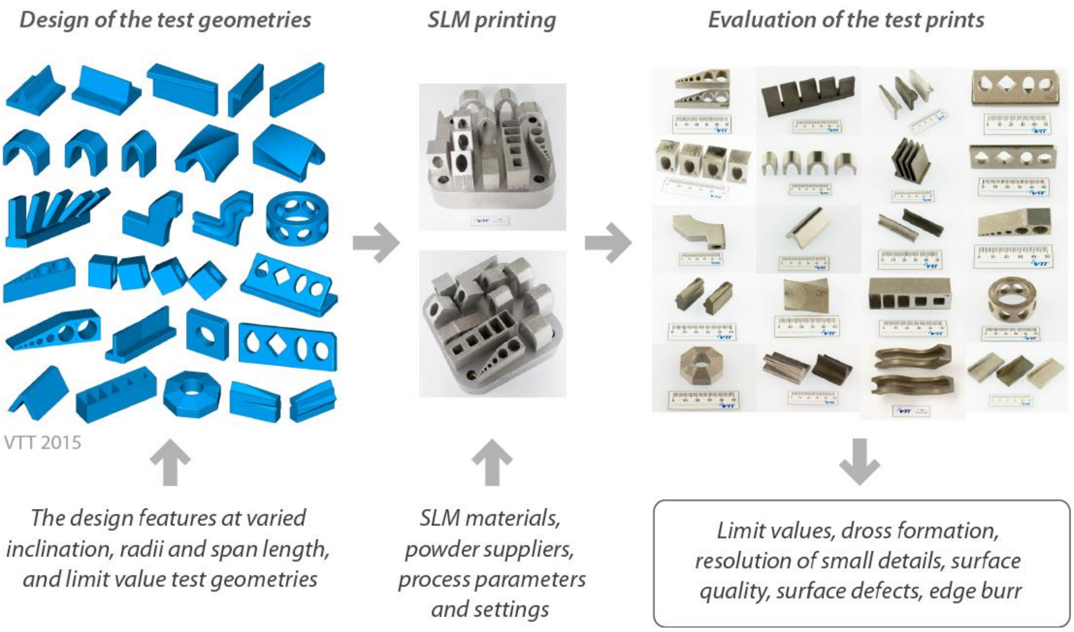

Figure 1. Systematic design and assessment of test prints for the basis of SLM design rules [2].

DESIGN FOR AM

A typical workflow for the design of components manufactured by AM is shown in Figure 2. Already in the first step of specifying requirements, AM process limitations (such as those produced in the SLM design guidelines) should be taken into consideration. In the concept phase, there is the opportunity to use advanced simulation and optimization tools to help minimize material usage which leads to direct cost savings in the form of reduced metal powder and printing time necessary. Some of these optimization techniques will be discussed in the following section. And while the design workflow appears linear in the diagram, it is most often an iterative process that produces not one final potential design but many.

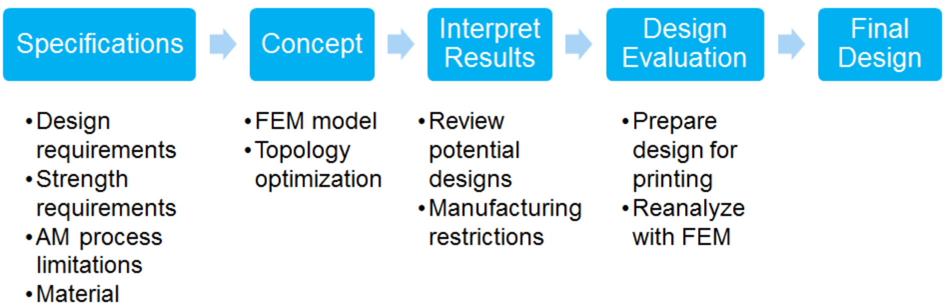

Figure 2. Overview of the design for AM workflow (adapted from [3]).

TOPOLOGY AND LATTICE OPTIMIZATION

Finite element based topology optimization is a technique used to find the optimal distribution of material and voids in a given design space, dependent on loading and boundary conditions, such that the resulting structure meets prescribed performance targets [4]. It is of most use in the early stages of the design process for concept generation, and works very well in suggesting the most efficient use of material in cases that do not have too many geometric restrictions. Thus it is often used for AM component design [3, 5, 6, 7, 8, 9, 10]. A typical topology optimization process and an example result are shown for a jet engine bracket in Figure 3.

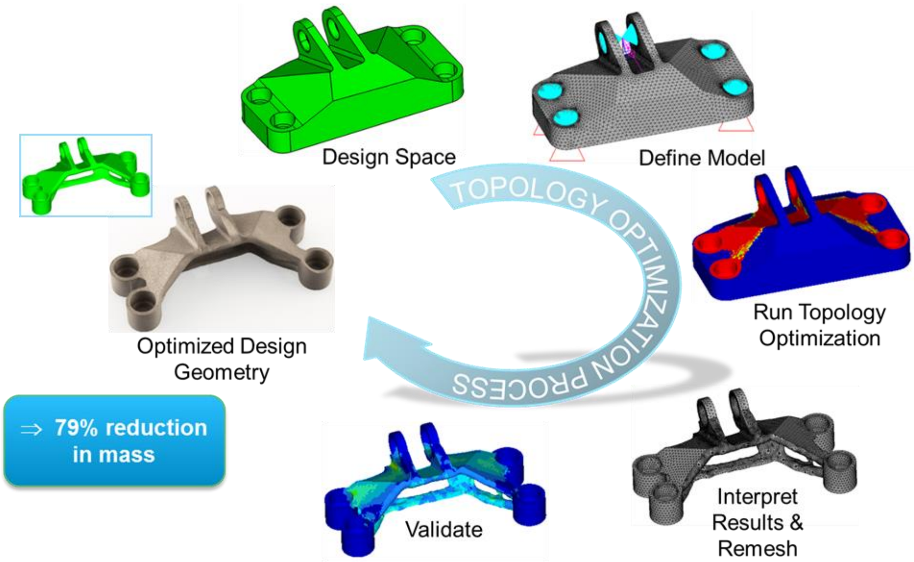

Figure 3. Description of the topology optimization process; jet engine bracket shown as an example [5].

Lattice optimization is an extension of topology optimization, whereby the design space is divided into an optimal distribution of material, void, and a repeating lattice structure. Size optimization is subsequently utilized to determine the minimum beam diameters necessary throughout the lattice structure. This technique is interesting for two main reasons; generation of lightweight structures and to reduce or eliminate the need for supporting structures that require removal after printing. Commercially available software such as Altair OptiStruct support lattice optimization, however the lattice structure beam elements generated are based directly on the finite element mesh. This is problematic as the produced lattices are not necessarily printable with AM. Work is being done to establish a straightforward workflow that includes replacement of the mesh-based lattice structures with a printable alternative.

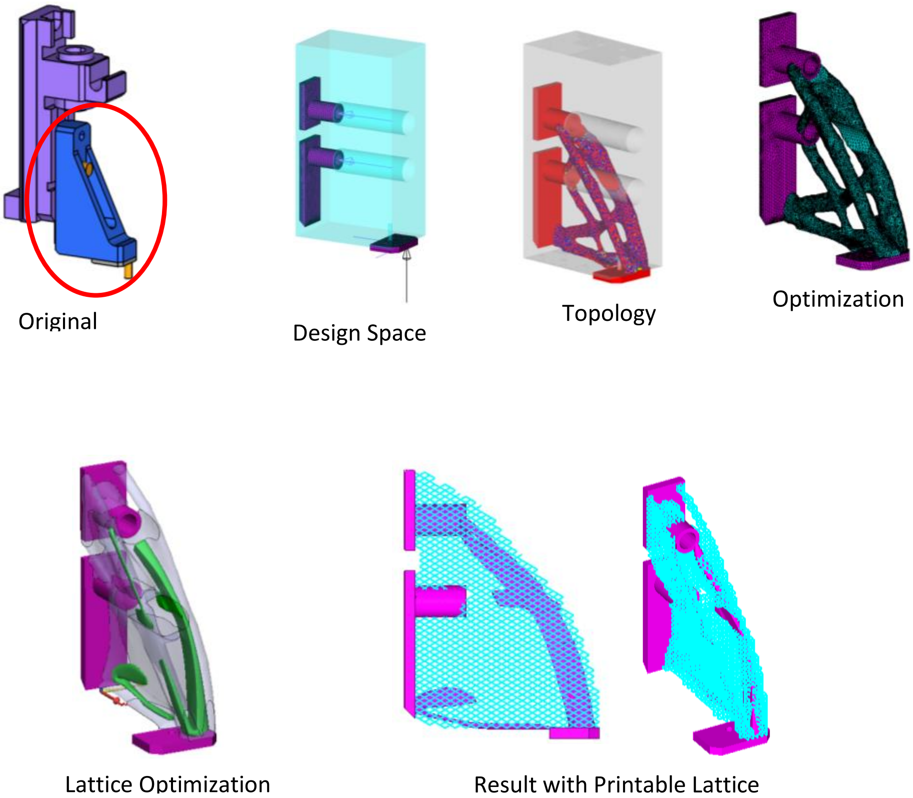

Figure 4. Topology and lattice optimization of a welding head bracket for Meconet Oy.

One case study coming from Meconet Oy, concerning the redesign of a welding head bracket from a multi-center machine, is described in Figure 4. In this example the goal was to reduce the mass of the component and thus the operating costs of the machine. Sample topology and lattice optimization results are shown.

3D PRINTED SANDCAST MOLDS FOR CAST METAL PARTS

A final topic of study is the use of 3D printed sandcast molds for the creation of cast metal components. This technique allows much of the design freedom offered by metal AM, while the actual part is produced through casting. Parts consolidation, functionality improvements, topology optimization, etc. can be used to take advantage of the geometric freedom offered, while casting simulation helps to ensure that the designed component can be successfully manufactured.

CONCLUSIONS

In order to take full advantage of the tremendous potential offered by AM, it is not enough to simply start printing existing components that can be manufactured by more traditional techniques. Components should be designed (or redesigned) specifically for the AM process that will be used. This will allow the creation of a final product that is some combination of functionally superior, customized, and lower cost than a component designed for traditional manufacturing processes.

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11. 3D PRINTING OF SOFT MAGNETIC CORES FOR ELECTRICAL MACHINES

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ABSTRACT

Soft magnetic cores of electrical machines are typically made of electrical steel sheets by stacking them together. In this work, we explore the possibilities of producing these cores through additive manufacturing, namely by selective laser melting. Utilisation of additive manufacturing offers freedom, e.g. in the machine design and potentially results in significant material savings. The results that we have obtained are encouraging; the key characteristics of our specimens mainly meet the requirements of commercial electrical machines.

INTRODUCTION

The first rotating electrical machine with a significant output power has been built already over 100 years ago. Reflecting the long history, the manufacturing methods and materials for electrical machines have become rather established. The active parts of an electrical machine typically comprise of coils, i.e. windings, soft magnetic cores and possibly of hard magnetic materials, i.e. permanent magnets. When it comes to the soft magnetic cores, these are typically made of electrical steel sheets by stacking them together. The sheets are cut are into suitable form through punching or by laser.

Recent development of powder bed processing of printing metals, e.g., through selective laser melting, is opening up interesting opportunities in the field of electromechanics, too (Wohlers 2014; Garibaldi et al. 2015). Selective laser melting is a process where objects are formulated by melting powder particles together layer by layer. Almost any material that can be welded is suitable for this process. However, the supply of commercial powder materials is not very wide but is increasing each year; at the present moment mainly different steels, titanium, aluminium, nickel, copper and cobalt-chromium alloys exist.

Application of additive manufacturing techniques in the production of soft magnetic cores, especially those of reluctance machines, appears interesting and potentially groundbreaking. Soft magnetic cores are used in electrical machines to guide the flux and to improve the performance. More comprehensive optimisation of the magnetic circuit, i.e. the stator and rotor cores of the machine, without the limitations of conventional subtractive and formative manufacturing methods, can result in designs with significantly enhanced performance and notably lower material consumption and costs. The former is particularly true for the transverse flux reluctance machines. (Gartner et al. 2011)

While the possible gains of utilising the 3D printing in the manufacturing of electrical machines have been lately addressed in some publications (Garibaldi et al. 2015), the number of practical examples presented in the literature is rather limited. In this work, we study the manufacturing of the soft magnetic cores through selective laser melting and perform a characterisation of the samples. Our main objectives are to explore: 1) how suitable typical materials of soft magnetic cores are for selective laser melting, 2) how well the characteristics of the printed samples meet the requirements of modern electrical machines. We organise our work by first presenting the methods, then the results and finally the conclusions.

METHOD

The design of the soft magnetic cores that were studied in this work was adapted from the literature. (Lee et al. 2010) Lee et al. studied the minimisation of the torque ripple and mass of the rotor of a switched reluctance machine through topology optimisation. The final design is rather different from that of a typical switched reluctance machine and therefore it makes a good candidate for additive manufacturing.

The work was carried out with VTT's SLM 125 HL machine the main characteristics of which are summarised in Figure 1. (SLM SOLUTIONS NA n.d.) As shown in Figure 1, the maximum build size is around 123x123x110 mm^3. Furthermore, the machine is capable processing various materials and suitable for their testing and development of different powder compounds.

The Fe-Co powder that was used in this work was prepared at VTT. Quite similar material compound as in our powder is used, for instance, in high quality electrical steels sheets of Vacuumschmelze, e.g. VACOFLUX 50. In order the printing to succeed, the particle size distribution should be between certain values to ensure good flowability of powder. In SLM powder bed process, component is build up layer by layer which means that maximum particle size of powder is commensurate to layer thickness. In this case, the maximum size of the particles was 63 µm.

Suitable printer parameters for processing Fe-Co powder were first searched based on the literature and through practical test. The aim here was to maximise the density of the parts. After the suitable parameters were found the actual test pieces, i.e. the topology optimised rotors of a switched reluctance machine and various test specimens for the magnetic, electrical, mechanical and structural characterisation were prepared.

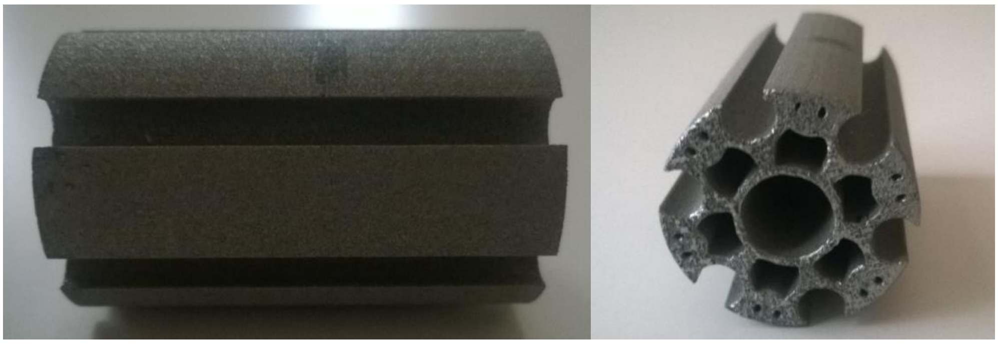
	**SLM 125 HL** Powder bed fusion technology Maximum build size: 123 mm x 123 mm x 110 mm Optimal for material development and testing Materials: e.g. stainless steels, tool steels, Inconel, cobalt-chromium, aluminium, titanium Laser: 400 W IR Manufacturing parameters adjustable

Figure 1 Key specifications of VTT's laser printer. (SLM SOLUTIONS NA 2016)

RESULT

The 3D printed soft magnetic rotor of a switched reluctance machine is shown in Figure 2.

Figure 2 3D printed rotor for a switched reluctance machine. The maximum outer dimensions of



the rotor are approximately 3 cm x 4.5 cm.

The *BH*-curves for the rotors are shown in Figure 3. As can be seen the saturation magnetic flux density is c. 2.3 T which is clearly compatible with the requirements of commercial applications. Analysis of the microstructure of the printed samples revealed that their relative volumetric mass density is above 99.9% which is a very good result, too. The electrical conductivity was measured to be in the range of 52 μohm/cm. Optimally, the resistivity of the soft magnetic cores should be higher to mitigate the losses.

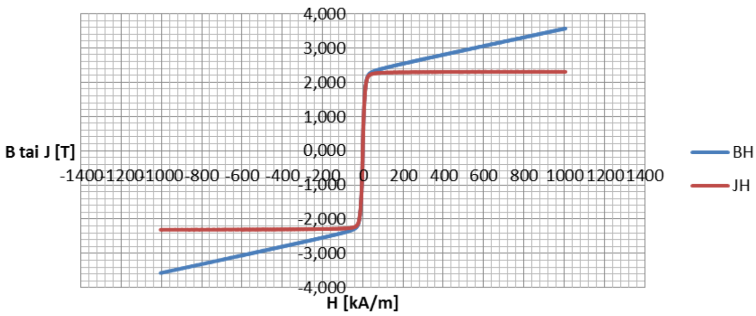


Figure 3 BH-curves of the 3D printed specimens.

CONCLUSION

We explored the possibilities of 3D printing in manufacturing of soft magnetic cores. The results that we have obtained are promising, i.e. the key characteristics mainly fulfil the requirements of soft magnetic cores used in electrical machines. Further work in the topic includes: comparison between different powder compounds, tuning the materials to increase the electrical resistivity and introducing the topology optimisation into our own design methodologies.

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12. IMPROVING THE MECHANICAL PROPERTIES OF SLM PROCESSED TOOL STEEL BY PROCESS OPTIMIZATION

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ABSTRACT

Additive Manufacturing (AM) technologies offer the capability to produce solid objects directly from a 3D model allowing the production of complex designs with advanced materials. The current generation of metal AM printers is technologically capable to answer the demand of the manufacturing industry but further advances in material research are required for the technologies to become more widely adopted. There are still many challenges in the field of metal AM in terms of having knowledge on material properties such as mechanical and chemical properties. This paper is a response to this lack of knowledge and it demonstrates the improvement of mechanical properties for printed H13 tool steel samples by process parameter optimization for maximum density. Selective Laser Melting (SLM) is used to print H13 tensile test samples in different orientations that are tested in three conditions; as built, stress-relief annealed and quenched and tempered. The optimization is done by printing 50 test samples (1x1x1cm) for which porosity measurements are performed and a numerical model is fitted to the measured density values. The parameters determined using the numerical model result in higher density and improved yield- and ultimate tensile strengths for the heat-treated samples that are comparable to conventionally manufactured samples.

INTRODUCTION

In the SLM process each layer can have separate predefined input process parameters and the most significant parameters in relation to the density of the finished part are laser power, scanning speed, hatch width and layer thickness (Hanzl et al. (2015)). Suitable parameters are typically provided by the machine manufacturers but only for a limited number of materials. In order to build dense, crack free parts with acceptable mechanical properties from less common powders, a well-defined set of process parameters is required. The objective of this work was to optimize the initial SLM process parameters (power, scanning speed, hatch width) to increase the density of the H13 samples and consequently the mechanical properties. The mechanical properties are determined by performing tensile tests.

EXPERIMENTAL METHODS

Commercial gas atomized H13 powder supplied by SLM Solutions GmbH was used for the production of the samples using the 125 HL selective laser melting system (400W laser) manufactured by the same company. The powder had a spherical shape and a narrow particle size distribution. The powder supplier provided process parameters for the powder that are referred to as “initial” parameters in this paper. Two sets of 25 samples were printed for parameter optimization and prepared (ground & polished) for optical imaging. Porosities were measured from the cross section images (1xmagnification) using Fiji image analysis. D-optimal design of experiments method was implemented to calculate the parameters for the samples. For the first sample set the power was kept constant at 175 W and for the second set the hatch width was kept constant at 100 µm. In the experimental designs the hatch width, scanning speed and laser power values ranged between 90µm - 150µm, 400 mm/s - 1200 mm/s and 100

W - 300 W respectively. A constrain was set to limit the parameter design space by choosing a volumetric energy densities between 50 – 100 J/mm^3 as this was a suitable range according to literature (Spierings et al. (2011)). The layer thickness in the experiments was 30 µm. The tensile test samples using initial parameters were printed in horizontal, 45° angle and vertical orientations relative to the substrate plate. Nine samples were built in each orientation and three samples in each build orientation were tested in the following condition: as built, stress relief annealed, hardened and tempered. Another set of nine tensile test samples was printed using the optimal parameters calculated based on the results of the DoE sample sets. The tensile tests were performed in room temperature.

RESULTS

The printed DoE test cubes and the tensile test samples are presented in Fig.1 a-b. A cubic polynomial function was fitted to the measured density data points and surface contour plots were drawn to help visualize the parameter design space (Fig.2. a-b).

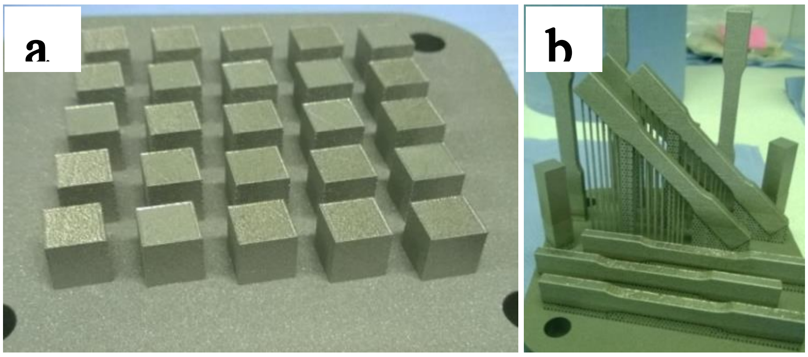

Fig. 1. a) 25 cubic samples used for parameter optimization, b) tensile test samples printed in three orientations.

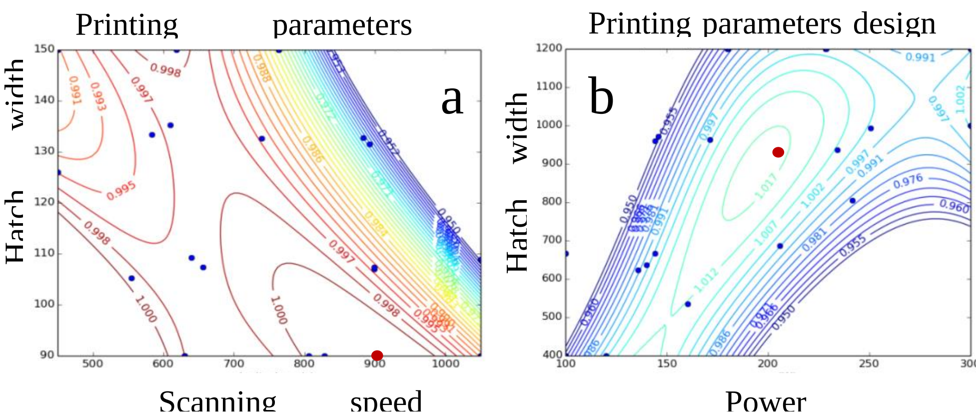

Fig. 2. a) Density contour plot with hatch width and scanning speed as process variables (Power = 175W) and b) density contour plot with scanning speed and power as process variables (Hatch width = 0,1 mm). The red dots represent the optimal parameters in each parameter design space.

The tensile test results are presented in Table 1. According to the results the build orientation seems to have an effect on the mechanical properties which can be best seen with samples tested in as built condition. The vertical build orientation resulted in highest yield and ultimate tensile strength values and horizontal orientation resulted in the lowest. The yield and ultimate tensile strengths for samples printed with initial and optimal process parameters are presented in Fig.3, showing the improvement of mechanical performance with optimal parameters.

Table 1. Mechanical properties of SLM built H13 tool steel. The results are reported as average values of three samples unless stated otherwise.

	Yield strength (Mpa)			Ultimate tensile strength (Mpa)			Elongation (%)		
	As built	Stress relieved	Hardened and tempered	As built	Stress relieved	Hardened and tempered	As built	Stress relieved	Hardened and tempered
Horizontal (optimal)	841	1155	1639	1298	1541	1723	1,9	5,7	0,9
Horizontal	784	1232	1553[1]	1333	1438	1612[1]	1,8	4,4	1,2[1]
45°	957	1214	1570[2]	1474	1432	1589[2]	1,4	4,7	1,2[2]
Vertical	963[1]	1166	1633[1]	1553[1]	1380	1714[1]	1,9[1]	7,7	1,1[1]
Reference			1520			1820			12

[1]One sample broke before 0,2% stain and was left out of the results
[2] Two samples broke before 0,2% strain and were left out of the results
[3] Reference values at room temperature

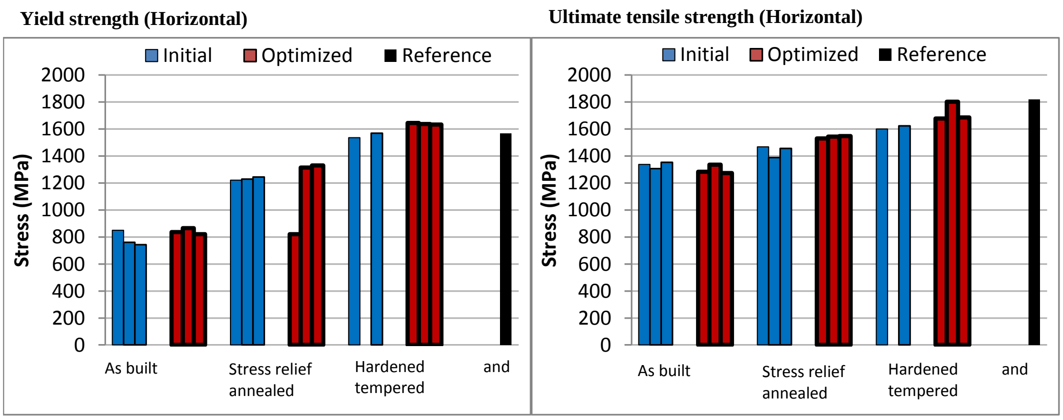

Figure 3 Yield and ultimate tensile strengths of horizontally printed H13 tensile test samples with different build parameters. The stress relief procedure was as follows: heating up to 650°C in two hours, holding at 650°C for two hours and cooling in furnace to room temperature. The hardening and tempering procedure: heating to 1030°C, holding for 30 min and then quenching in oil (50°C). After quenching the samples were tempered twice at 400°C for 2 hours and cooled in air. The reference sample: conventionally manufactured Uddeholm Orvar supreme tool steel. Reference sample hardened for 30 min at 1025°C, cooled in air and tempered (2h+2h) at 610°C (Uddeholm (2013)). Elongation reference (Uddeholm (2010)).

CONCLUSIONS

Porosity reduces the mechanical performance of materials and should therefore be minimized. In the SLM process the selected parameters affect the behaviour of the molten material (Gong et al. (2014)) and consequently the defect density in the finished part. This paper presented a method for optimization of the selected process parameters that ultimately led to improved mechanical properties in SLM processed H13 tool steel. With the DoE method it is possible to define the parameter window leading to high density with a relatively small amount of samples making it a cost-effective approach. This approach could be implemented to optimize the SLM process for any material. The mechanical properties are defined for a relatively small number of materials as the material development advances more rapidly for materials with most industrial significance (Lewandowski and Seifi (2016)). There is a demand for future research in gaining better understanding on material properties such as corrosion resistance and fatigue strength that are important topics in the AM field.

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13. MODELING OF THE PROCESS PARAMETERS INFLUENCING COLD METAL TRANSFER (CMT): DEVELOPMENT OF AN APPROACH BASED IN CAUSAL NETWORKS

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ABSTRACT

The new Additive Manufacturing technologies combined with other transformations such as increasing digitalization and automation are creating new opportunities and associated challenges. For all the AM technologies, both functional and topological design of parts need to be completely reconsidered, for example, it becomes possible to integrate multiple functions into a single part. From the manufacturing process outlook, the links between process parameters and design requirements have to be unveiled. Discovering those links is a challenging process because of the existence of cross-impacts. The nature of the relationships is also probably highly nonlinear in some cases. Using a traditional design of experiment approach to discover those links might be time-consuming and the number of parameters to test might be enormous. This article applies an approach based on SI metrics combined with the functional representation of the manufacturing process to form causal-graphs. Those graphs are used in a preliminary phase to generate models of the interrelations between manufacturing and design parameters. Those models are also used to guide the experimental process and to minimize the amount of experiments to be conducted to validate the model. The approach is applied to the Cold Metal Transfer (CMT) technology currently in test in our laboratory.

INTRODUCTION

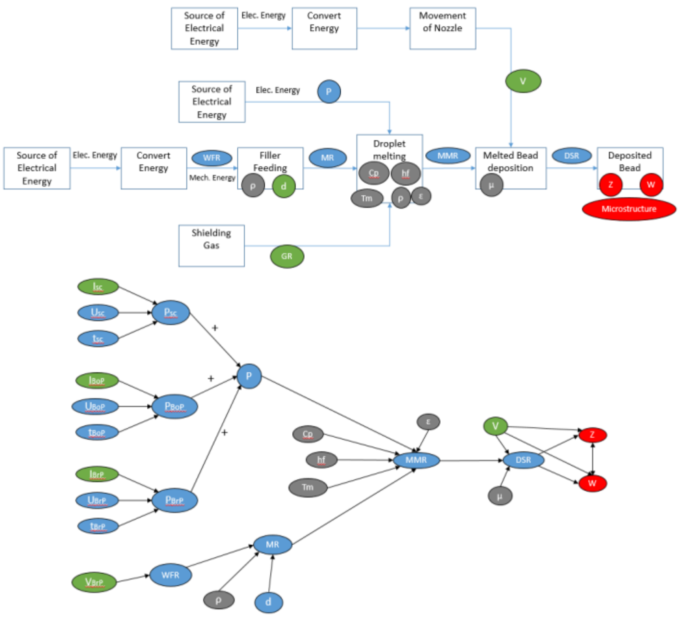
Dimensional Analysis Conceptual Modeling (DACM) is a method formed from validated traditional modeling methods such as function modeling, dimensional analysis, bond graphs and causal rules. [1] The aim of the DACM Framework is to present a network-based causal model between system variables. The method can be applied to an already existing system or to a completely new system in the conceptual design phase. The framework also plans to optimize the experimental process so that less experiments are required to gather required knowledge. It tries to find the most influential parameters for the system and also the negligible ones. [2] Using the framework requires great knowledge of the process as well as the phenomena's occurring in the system. If the system is not fully understood and some influential variables aren't introduced in the model, it can affect the results and make the model unreliable. In the best scenario the model created by DACM framework can be used as a guideline for the experimental side of the work and the amount of experiments can be reduced that is needed to validate the model. The framework is presented more closely in our case study. The aim of this study is to find the most influential parameters in Cold Metal Transfer (CMT) process. The CMT is a welding process developed from traditional arc welding method by Fronius and benefits, when compared other arc methods, lie in the low heat input and almost spatter free processing. CMT process can be considered to include cycles, these cycles have three different phases; short circuit phase, where the droplet is detached; boost phase, where the arc is ignited again and the wire starts to from a melted droplet on the tip; burn phase, where the wire feed rate increases until the wire touches the weld pool and the short circuit begins. [3]

CASE STUDY

In this article, the method is applied to arc welding method called Cold Metal Transfer (CMT). Table 1, the variables of the system are listed with their dimensions and picture 1 depicts the functional presentation of the system. The functional graph is a simplified presentation of the system. Every action of the process is presented by a box, which includes the type of action and the variables that have effect on the action itself.

Parameters	Symbol	Unit	Dimension	Parameters	Symbol	Unit	Dimension
Short Circuit current	I_{sc}	Ampere	A	Computed average wire feed rate	WFR	m/s	LT^{-1}
Short circuit voltage	U_{sc}	Volt	$ML^{-2}T^{-3}A^{-1}$	Mass flow rate of filler	MR	g/s	MT^{-1}
Short circuit duration	t_{sc}	second	T	Melted material feed rate (joule.gram)	MMR	g/s	$M^2L^2T^{-3}$
				Bead Deposited surface rate	DSR	m^2/s	L^2T^{-1}
Boost Phase current	I_{BoP}	Ampere	A	Nozzle travel velocity	V	m/s	LT^{-1}
Boost Phase voltage	U_{BoP}	Volt	$ML^{-2}T^{-3}A^{-1}$				
Boost Phase duration	t_{BoP}	second	T	Density	ρ	Kg/m^3	ML^{-3}
				Viscosity	μ	Pa.s	$ML^{-1}T^{-1}$
Burn Phase current	I_{BrP}	Ampere	A	Melting point	T_m	°C	t
Burn Phase voltage	U_{BrP}	Volt	$ML^{-2}T^{-3}A^{-1}$	Specific Heat Capacity	C_p	joule/g°C	$L^2T^{-2}t^{-1}$
Burn Phase duration	t_{BrP}	second	T	Heat of fusion	h_f	Joule/g	L^2T^{-2}
Velocity of filler in Burn Phase	V_{BrP}	m/s	LT^{-1}	Shielding gas flow rate	GR	m^3/s	
				Arc Length Correction	ALC	-- (%)	
CMT full cycle time	t_{CMT}	Second	T	Absorbtivity	ε	--	
Imported power to system	P	Watt	$ML^{-2}T^{-3}$	Filler diameter	d	m	L

Table 1. List of process variables



Picture 1. Functional presentation and bond graph of the system.

After creating the functional presentation of the system, a bond graph is created by exploitation of causality rules. [1] As it can be seen from the graph, there are several parameters, metal or process related parameters, effecting the bead thickness Z and therefore on the material properties as well. The bond graph enables to extract the causal relation between the system variables. These variables are presented with different colors, black, green, blue and red. Black is exogenous variables that cannot be changed unless changing the borders of the system. Green is for independent variables. Variables that are difficult to control or are affected by other variables in the system are colored in blue, dependent variables. Red are the target variables, the ones are used to evaluate the system, also known as performance variables These variables are being tried to either minimize, maximize or set target value. The causal relations between the variables and their units enables the construction of the model's behavioral laws. These laws are developed using dimensional analysis approach. Dimensional analysis is an approach where the complexity of modelling problems is reduced. [2] It uses the dimensions of the variables and tries to conclude the relationships among the variables by creating dimensionless products. These equations for each variable is presented below on the left. These dimensionless groups can be combined together according to Vashy-Buckingham's Π-theorem [4] to take a form the equations on the right:

$$\pi_{P_{SC}} = P_{SC} \times \frac{t_{SC}}{t_{CMT}}^{-1} \times I_{SC}{}^{-1} \times U_{SC}{}^{-1} \qquad \pi_{MR} = MR \times WFR^{-1} \times \rho^{-1} \times d^{-2}$$

$$\pi_{P_{BoP}} = P_{BoP} \times \frac{t_{BoP}}{t_{CMT}}^{-1} \times I_{BoP}{}^{-1} \times U_{BoP}{}^{-1} \qquad \pi_{MMR} = MMR \times P^{-\frac{5}{2}} \times (h_f \times C_p)^{\frac{9}{8}} \times \rho^{\frac{1}{2}} \times T^{\frac{9}{8}} \times \varepsilon^{-1}$$

$$\pi_{P_{BrP}} = P_{BrP} \times \frac{t_{BrP}}{t_{CMT}}^{-1} \times I_{BrP}{}^{-1} \times U_{BrP}{}^{-1} \qquad \pi_{DSR} = DSR \times MMR^{-\frac{1}{3}} \times \mu^{\frac{2}{3}} \times V^{-\frac{2}{3}}$$

$$\pi_P = \pi_{P_{SC}} + \pi_{P_{BoP}} + \pi_{P_{BrP}} \qquad \pi_Z = Z \times DSR^{-1} \times V$$

$$\pi_Z = f(\pi_P, \pi_{MR}, \pi_{MMR}, \pi_{DSR})$$

$$\pi_Z = K \times \pi_P^{\alpha} \times \pi_{MR}^{\beta} \times \pi_{MMR}^{\gamma} \times \pi_{DSR}^{\delta}$$

Those exponents, α, β, γ and δ, and the constant K should be defined by heuristic reasoning, Scaling law-algorithm and experimental test. SLAW is based on the scaling laws and it has two main abilities. [5] First is to rank the importance of the system variables and second is to find the simple scaling law that rules the engineering problem. Heuristic reasoning is the one that should be done first since it's based on the summation of theoretical and technical knowledge combined with common sense. [6] Experiments that will be conducted can verify model as well as show the real influence of the parameters. The design of experiment by Taguchi approach is used to find those influences and exponents of our equations. This research will continue by conducting experiments to verify the model.

CONCLUSIONS

This article presented a modeling method that combined several design methods, such as functional modeling, bond graph and dimensional analysis. The approach was conducted on developed metal arc welding process called CMT. Benefits of the modeling method lie in the visualization of the system and the causal relationships between variables. These causalities between variables are verified by doing design of experiment by Taguchi, which will be the next step of our research.

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III Smart Machines and Robotics

14. SENSOR-ASSISTED FLEXIBLE INDUSTRIAL ROBOT WORKCELL: A CASE STUDY

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ABSTRACT

Industrial robots are operated in the factories to support the production line for assembly, material handling, inspection, etc. Use of auxiliary devices on the robot arm has been a trend for decades. Moreover, with advances in sensor technology and development of control systems, robots become more flexible and handling the tasks is more intelligent.

This paper presents the concept of flexible industrial robot workcell which consist of industrial robot equipped with affordable price commercial 3D/2D vision sensor (Kinect v2), electrical nut runner and pneumatically controlled magnetic gripper. Communication between the robot and vision sensor is realized by ROS-Industrial interface which can be used to communicate with other devices as well. The workcell was demonstrated as an autonomous ground vehicle (AGV), in this case a wheel loader, service station. In the demonstration maintenance operations were done to the AGV without using additional fixtures by locating the loader and its parts by sensors. The results show that use of the sensor system increases the robot system flexibility and the sensor assisted cell can be built with low cost commercial products. The demonstration showed that technical challenges can be solved with proper design and programming. The methods presented can be used widely in robot operations in manufacturing industry.

INTRODUCTION

Use of industrial robots in different tasks in production and other fields is constantly increasing. Advances in sensor technology, development of control systems and artificial intelligence, have enabled robot cells to become more flexible and intelligent. Making machines to interact with the physical world requires direct information of the surrounding objects by sensors and machine vision. Decreasing costs of sensor technology have increased the use of sensors in robot workcells during recent years.

As part of "TUT Robotics and Intelligent Machines" (TUT-RIM) project we studied and demonstrated flexible industrial robot workcell. In this paper we present the case study tasks, system design of the workcell and some key findings of the study.

RELATED WORK

Using robot manipulators for different tasks is an essential part of the modern factories. Optimization of a single assembly task using modular work planning has been approached representing concept models (I-ming et al., 1995). Multi-robot tasks are intended to make collaboration for a common assembly task using synchronized control systems (Sun et al., 2002). On the other hand, reaching a higher flexibility can be possible by flexible sensory data and auxiliary devices. Jörg et al. (2000) define two main factor for cell design which includes using all sensor capabilities and simple operation of the system. Imposing force control into robot system derives a better approach to assembly without doing any harm to the original workpiece (Jörg et al., 2000).

Object recognition and pose estimation from 3D data (point cloud/colored point cloud) is an active yet challenging problem in robotics, e.g. for vision based manipulations (A. Buch et al., 2013) and determining navigable terrain (R. A. Newcombe, 2011). There exists number of different pose estimation methods but in this work we will focus on model-based 3D-3D correspondence pose estimation.

Robot systems have been in need for a common language for communicating between different system parts. Various robot manufacturers create own control systems which use particular own defined languages. Comprehensive robotic system implementations require a framework that can handle different plugins for implementing robots, planners, controllers, and sensors. ROS (Quigley et al., 2009) is one of the most famous robot architectures for communicating between system hardware and software modules as well as multi-robot cooperation. ROS has the capability of multi-language programming and is open source.

CASE DESCRIPTION AND SYSTEM DESIGN

Whole multi-robot worksite has three task phases: work phase where AGV levels the ground, a quality inspection phase where a micro air vehicle checks the levelling quality, and a service phase where an industrial robot changes the broken blade edge on the AGV to a new one.

When the AGV has navigated to the service station the vision system checks by RGB-D sensor that the blade is in suitable pose for service. If it is not reachable by the industrial robot, the AGV is requested to reposition the blade appropriately. After the pose is correct the RGB-D sensor locates the blade. According the RGB-D assessment the industrial robot moves the vision system closer to the blade and the bolts on the blade edge are localized more accurately by a 2D RGB sensor. The industrial robot opens the bolts with a nutrunner and changes the blade edge to a new one with a magnetic gripper. When the changing operation is ready the service station notifies AGV that service is completed and it is free to leave from the service station.

The service station is operated by an industrial robot manipulator (ABB IRB 4600). The robot is equipped with nutrunner, magnetic gripper system and a vision sensor. Communication between the robot and vision sensor as well as other devices is implemented through ROS.

The nutrunner is used for unscrewing and screwing the bolts on the AGV blade. The locations of the bolts are received from vision system. A special search routine is programmed for the robot to locate a bolt if it is not exactly in given location. The robot confirms the bolt location with torque sensor integrated in nutrunner. The pneumatic magnets are used to hold parts in position while working on them, to detach and to attach parts. The magnetic gripper system consists of three pneumatically controlled magnets. The magnetic state can be turned on and off with an air pulse. One of the magnets is fixed to manipulator tool end. With that the robot can pick separate magnet system which is used to hold parts in position, to detach and to attach parts.

The depth sensor used in the workcell is the low-cost Kinect v2 sensor. The sensor generates 512×424 colored depth maps and it is mounted on the gripper of the robot. Hand-eye calibration is used to compute the spatial relationship between the camera and the robot coordinate system.

The whole external sensing system is interfaced to ROS running on a Linux. The interface consists of two components: depth image generator and workcell sensing intelligence. The worksite sensing intelligence component is responsible for the communication between the service station industrial robot and the actual computation needed to recognize the blade.

Inputs/outputs of nut-runner are connected to the robot controller, and robot tasks are programmed in RobotStudio, the offline programming tool for ABB robots. ROS-Industrial packages are installed on ABB controller to distinguish ROS functions definitions. When the estimated pose is sent by Kinect, ROS opens a port and sends the location of the blade or bolts to the robot controller. Status of the robot is being updated by receiving feedback from the controller to avoid sending new requests when the robot is busy with other tasks.

DISCUSSION

In the demonstration, pose estimation algorithm was used successfully for locating and opening the bolts. The pose estimation process was rather slow (about 10s), but in real world implementation it can be shortened to few seconds or even under one second by using parallel programming on GPU. That would though need a lot of more programming work. Using the magnets for removing and replacing the blade edge was found challenging due to “hoseless” operation and the design of the magnet system requires more work to enhance the robustness against inaccuracies of the Kinect sensor.

The system proposed in this paper is able to be extended for other similar stations. Mixture of a pneumatic tool beside the vision system creates a flexibility on the job type for screwing bolts, assembly tasks, loading, etc. in industry.

In the future we are planning to use group of sensors to increase the accuracy and reliability of the sensor system. In this work task implementations were mainly integrated in robot controller. The plan is to move these functions to ROS as this will bring higher flexibility for programming of new tasks.

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15. IMPROVING CONDITION MONITORING METHODS FOR AN FIGHTER AIRCRAFT MAIN LANDING GEAR SHOCK ABSORBER

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ABSTRACT

The most used shock absorber type in an aircraft main landing gear is an oleo-pneumatic (air-oil) shock absorber. The shock absorber takes the brunt of the force generated due to a landing and dissipates it. After consecutive landings the shock absorber requires servicing. This is a time and resource consuming operation and the aircraft is out of operation during that time. The operational downtime can be reduced if the time interval between services can be prolonged. This can be achieved, if there is better knowledge of the operation and behavior of the shock absorber. However, comprehensive testing requires considerable time and resources, so modeling and simulation is adopted as a tool to study the shock absorber operation. In this article, a simulation model of the shock absorber and its use in condition monitoring is discussed. The model is validated with experimental data. With the model a comprehensive study of landings with different sink speeds, gas-oil ratios, gas temperatures, and pressures can be made.

INTRODUCTION

An oleo-pneumatic shock absorbers has gas, commonly dry air or nitrogen, acting as a spring and liquid that flows between two chambers through an orifice that is restricted by a metering pin so that a damping effect is had. The cross section of the metering pin is usually varying so that designed load-stroke curve is achieved. During compression, the restricted flow dissipates the energy of the shock associated with landing and a part of it is stored in the compressing gas, which is released during the rebound. In this case the shock absorber has an additional gas chamber with high pressure.

STATE OF THE ART

As oleo-pneumatic shock absorbers have become common after the Second World War, there are a plethora of studies about oleo-pneumatic shock absorber modeling. Usually the shock absorber is modelled isothermally during ground handling (Currey, 1988) and polytropically during landing (Milwitzky & Cook, 1953; Daniels, 1996; Horta et al., 1999). Also, the discharge coefficient associated with the orifice flow has a significant role in the damping ability of the shock absorber (Milwitzky & Cook, 1953; Yadav & Ramamoorthy, 1991). Friction has been succesfully modelled using the Karnopp friction model (Daniels, 1996; Horta et al., 1999).

STRUCTURE OF THE SHOCK ABSORBER

The structure of the shock absorber is shown in Figure 1. The main parts are the orifice support (1), the primary chamber (2) and the secondary chamber (3). The primary chamber has liquid inside it and the liquid flows between the primary chamber and the orifice support through and orifice and the gas inside the orifice support is compressed. The secondary chamber holds gas and acts only, if the landing is rough enough i.e. landing on an aircraft carrier or with heavy load and sink speeds. The main components of the equation of motion are those of friction, gas spring, and damping. As there is high pressure inside the shock absorber, seals and elastic packings are pressing firmly the surrounding parts. Therefore, increasing the initial gas pressure inside the shock absorber contributes also through friction to the required compression force. A full documentation of the shock absorber and a realistic analytical model can be found in Heininen (2015).

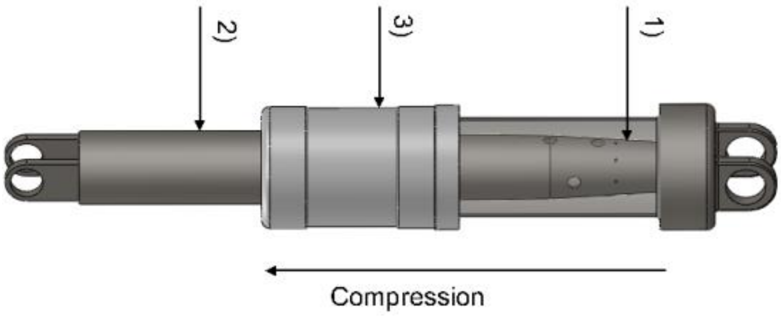

Figure 1. The structure of the shock absorber: 1) the orifice support 2) the primary chamber 3) the secondary chamber.

VALIDATION

Two types of experimental data were available for the shock absorber model validation: force-displacement measurements from a quasi-static test bench and measured inside pressure from a real landing. The simulated and measured normalised data from the test bench are shown in Figure 2. In Figure 3, the simulated and measured normalised pressure inside the low pressure chamber during landing is shown.

The simulation of the shock absorber behaviour in the test bench is in close agreement with the measured force-displacement curve. The pressure inside the low pressure chamber is not correct after the initial touchdown, but as the touchdown is the most important part of the landing, the results are acceptable. Some effects like leakage during landing and lift generated by the wings are not included in the model, which explains the differences. More detailed validation procedure can be found in Heininen (2015).

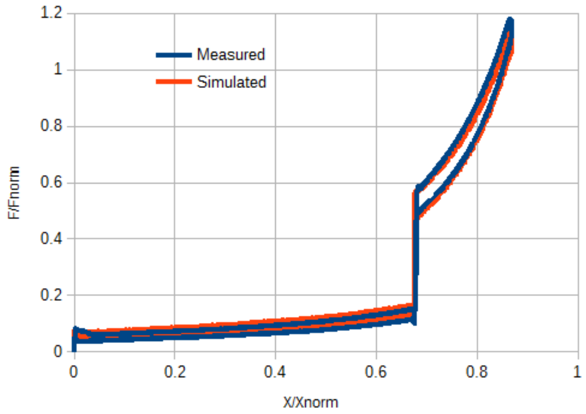

Figure 2. Measured and simulated test bench force-displacement curve.

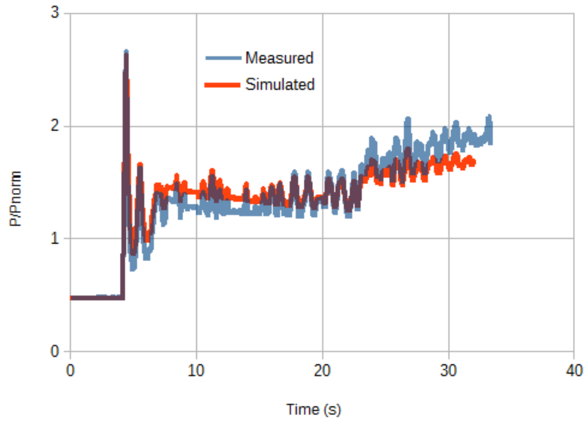

Figure 3. Pressure inside the low pressure chamber during landing.

DISCUSSION ON CONDITION MONITORING METHODS

After landing the shock absorber pressure is checked. If the pressure is lower than a certain level, gas is added to it. This changes the gas-liquid ratio and affects the stiffness of the shock absorber. After several landings the shock absorber is serviced i.e. it is removed from the landing gear, fluids are removed, and the shock absorber is inspected. All of this takes time and the aircraft is out of operation during it. If the service time can be shortened, it would reduce the upkeep costs and would make the aircraft operational for longer periods of time. At this time, the service period is based on experience and it is not known, what is the optimal service interval.

The simulation model can be used to analyse the behaviour of the shock absorber with different initial pressures, temperatures, and the gas-liquid ratios. The simulation results can be used to define normal operation and behaviour of the shock absorber and use that information to define accurate service intervals. These would be time and resource consuming to do only by performing experiments. However, one requirement is that a better pressure and temperature measurement unit is applied on the shock absorber, as it currently has only an inaccurate pressure gauge. The idea is that if the pressure differs from what is estimated normal behaviour during landing, the shock absorber needs servicing.The shock absorber model can be integrated into a larger landing gear model so that lift, tire stiffness and other effects can be taken into account, this is done in near future.

CONCLUSION

A realistic analytical shock absorber model has been created and validated. This model can is integrated into a larger landing gear model that as of date is not ready, but in the near future it is going to be used to simulate landings with different initial pressures, temperatures, and sink speeds. The data is then validated through measurements and used to define accurate service intervals.

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16. AUTONOMOUS MULTI-ROBOT WORKSITES: A TECHNOLOGY READINESS AND CASE STUDY

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ABSTRACT

Automation and autonomy is increasingly applied in heavy mobile machines or robots deployed e.g. in the forestry, mining, and civil engineering industries. Cooperation between multiple autonomous robots has potential to further increase productivity and improve operational safety. In this paper we investigate the concept of an autonomous multi-robot worksite. At the worksite, a fleet of heterogeneous robots cooperates to achieve a common goal. We identify the general requirements for realizing such a worksite, and present a specific case in the domain of civil engineering. The worksite concept was carried out in a real-world scenario involving a wheel loader, a micro aerial vehicle, an industrial robot, and supporting sensing and communication infrastructures. Communication interface was developed to enable an autonomous cooperation between aforementioned robots. In the current state the developed system works in semi-supervised environment and gives promising basis for further development. The results indicate that although separate components can work individually, there still remain challenges with reliability of fully integrated system consisting of autonomous robots.

INTRODUCTION

In this paper we present our work related unsupervised intelligent machines and robotics with multimodal sensors, machine-to-machine communication and autonomous task coordination. The work is done under TUTRIM-project that is a collaborative project between departments of Intelligent Hydraulics and Automation (IHA), Automation Science and Engineering (ASE), Mechanical Engineering and Industrial Systems (MEI) and Signal Processing (SGN). The target is to demonstrate the scientific research field where a "multirobot worksite" unsupervised operates together via communication and centralized or decentralized coordination and operation to perform given tasks robust to dynamic environment and surprises (e.g. mechanical failure). We describe the overall demonstration environment and scenario that will take place. Robots and their capabilities are briefly explained. Possible challenges related to such co-operation are discussed.

ENVIRONMENT AND CASE DESCRIPTION

In our research case we have three individual components that are integrated together. A first component is an autonomous ground vehicle (AGV), whose initial task is a ground levelling. After AGV has finished levelling a micro air vehicle (MAV), inspects the quality of the work done by the wheel loader. If quality of levelling is not satisfactory AGV is requested to seek maintenance. The service station, which consists of an industrial robot and a RGBD-camera attached to its gripper, is notified and AGV drives to the service area. While AGV is driving MAV explores the environment for possible obstacles on AGV's paths, using stereo camera system onboard. When AGV reaches the service area it docks with the service station where the plow is inspected and blade edge of the plow can be changed if needed. After the service has finished AGV undocks and returns to work. The test area layout is presented in the following Figure 1.

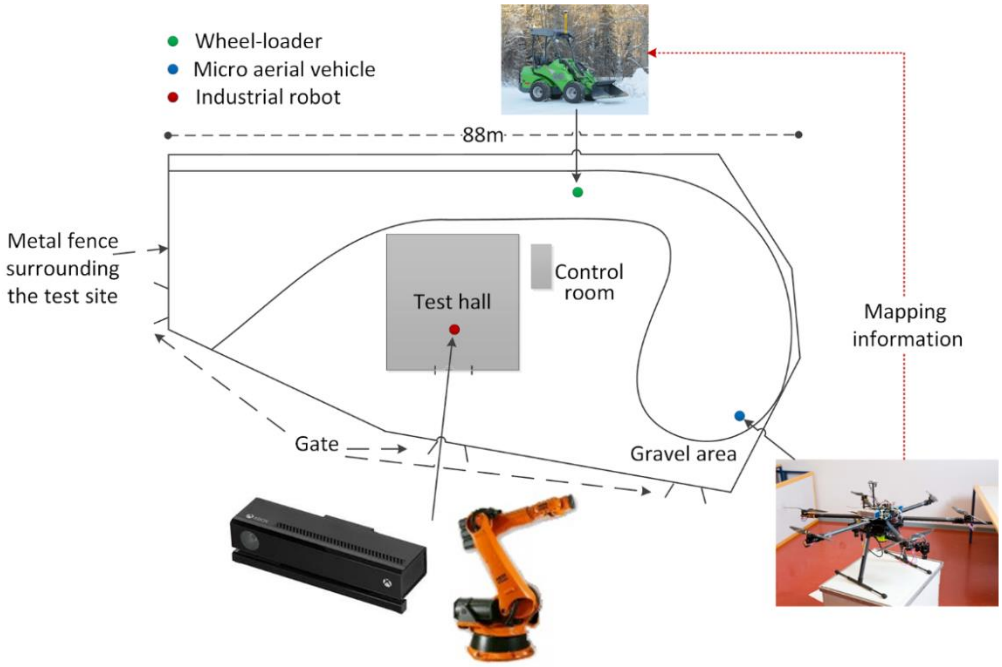

Figure 1. Layout of the test area and presentation of different robots involved in the demonstration.

WLAN that covers the test site is used for communication infrastructure between the robots. For communication purposes we are using Robot Operating System (ROS) and fkie communication package developed by Fraunhofer FKIE. Each robot operates and communicates using ROS.

The autonomous wheel-loader AGV is based on a modified Avant small sized multipurpose wheel-loader. The electronic and hydraulic systems as well as the control system of the wheel loader has been modified to enable electronic control of actuators, enabling autonomous operation. AGV is equipped with ECUs that control the low level systems. Additionally, two PCs onboard are used for higher control level operations such as localization, mapping, path planning and autonomous driving. For the localization of the AGV GNSS, IMU and wheel odometry are used. Sensor fusion is used to obtain accurate localization data.

The mapping module is described in greater detail in (Kolu 2015) and for further details on the path planning module, we refer the reader to (Choi 2016).

The MAV used in this work is a hexacopter equipped with basic flight control electronics, a small computer running Linux and two machine vision cameras in a stereo camera configuration.

The MAV is able to execute inspection and exploration tasks, which are initiated by the AGV. In inspection task the hexacopter receives a position in which the quality of the ground leveling should be inspected. The MAV flies to the position and takes an image pair of the ground below. From the stereo image the 3D-representation of the ground is calculated and work quality is compared to quality requirements. In exploration task the MAV creates a 3D-representation of ground in given route, which is then used by AGV's mapping to find possible obstacles.

The service station is operated by an industrial robot manipulator (ABB IRB 4600) and the robot is equipped with a nutrunner and magnetic gripper system. Robot controller is running ROS Industrial server to communicate with the other system components. The sensor used in the project is the low-cost Kinect v2 sensor which outputs a 512x424 colored point cloud and it is attached to the robot gripper using a hand-eye configuration.

The intelligent vision system consists of two components: depth image generator (Wiedemeyer 2015) and worksite sensing intelligence. The worksite sensing intelligence is responsible for the communication between the robot and the actual computation required to recognize the object. The industrial robot responsibilities are to locate workpieces according to the vision information acquired by Kinect and control the nutrunner and the pneumatic magnets for the tool change.

DISCUSSION

Creating robust network connections between the individual robots can be very challenging in worksite environments. As the physical environment changes also the wireless communication environment changes and blind spots may occur on some areas of the site preventing communication completely. Because these communication breaks will occur the system must be able to recover from short breaks. Also because the communication is unreliable the individual robot must be able to operate independently. In the other hand they must also use the information of other robots in the network to operate efficiently.

One challenge for AGV and also MAV is the localization indoors. Even though IMU, odometry etc. can be used without any global reference, the localization will slowly start to drift if none is present. Thus in outdoor conditions GNSS is widely used to provide global reference. In indoor conditions a separate localization system would be needed and this would require additional infrastructure on the worksite.

The worksites are normally operated by humans so they are also designed with that in mind. When bringing autonomous machines in such environments they must also be designed with the human perspective in mind. If the worksite would be fully autonomous it could also be designed in different way. This also goes with autonomous machines. Autonomous work machines are many times retrofitted to work as autonomous and originally they were designed for human drivers.

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17. HANDS-ON EXPERIENCE IN REMOTE OPERATION

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ABSTRACT

Remote operation is receiving an increasing interest in the context of work machines as a way to increase productivity and safety. Also, the level of autonomy of work machines is increasing, which changes the focus of operator work from controlling to only monitoring the operations. To transfer successfully from traditional on-the-spot work to remote operation requires parallel design of new work practices and tools. We have applied a user experience driven design approach successfully in a study where we designed a remote operation station concept for container cranes in ports. The concept was designed based on a user experience vision of "hands-on experience in remote operation" and four distinct user experience goals. In this paper, we briefly describe the design process, discuss the results, and consider some general human factors issues of remote operation.

INTRODUCTION

In remote operation (RO, or 'teleoperation'), a machine is controlled from a place where the operator does not have a direct sensory contact to the machine (Sheridan, 1992). Instead, the operator uses different kinds of cameras, sensors and other technologies to receive information about the remotely operated machine and its environment. This type of RO is utilized especially in safety-critical environments, for example, to increase worker safety and job satisfaction.

Early application domains of RO range from space operations to remote mining. Lately, RO has also been utilized, for example, in aviation (e.g., unmanned aerial vehicles), traffic (e.g., automated metros), and ports (e.g., automatic stacking cranes). The challenges in the design of remote operation systems for different domains vary. From the operator perspective, the problems may relate, for example, to 1) vigilance and boredom due to the supervisory work's monotonicity, 2) creating a comprehensive operational picture of the prevailing situation, and 3) latency time in teleoperation (see e.g., Wahlström et al., 2015). In this paper, we describe how RO has been applied to container cranes in ports, present a case study on user experience (UX) driven concept design of a remote operator station (ROS) for cranes, and consider some general human factors issues of RO.

REMOTE OPERATION OF CONTAINER CRANES IN PORTS

Container handling in ports is changing radically driven by new requirements for port efficiency, safety and worker well-being. As a solution to these requirements, some ports have taken into use new remote operation solutions, which also include high-level automation. Compared to traditional operation from the cabin in the crane, these solutions offer, for example, the following benefits:

- Efficiency and productivity increases, as one remote operator can control several cranes
- Semi-automated cranes sort containers in normal situations autonomously and optimally

- Human operator work's level of physical ergonomics increases (to an office environment)

However, RO solutions for container cranes may also pose some threats. Especially from the cognitive ergonomics and safety point of view, for example, the following issues may arise:

- The remote operator has only limited video camera views to the area where the containers are loaded and unloaded to trucks (i.e., the loading zone), which might have a detrimental effect on the operator's capability to detect potentially dangerous situations quickly
- If not designed properly, the remote operator's work may include only repetitive tasks and a work routine may develop, which does not take into account the details of various situations
- The remote operator cannot directly feel and hear what is happening in and around the crane

CASE: UX-DRIVEN CONCEPT DESIGN FOR CRANE REMOTE OPERATOR STATION

In addition to consumer products, the importance of user experience (UX) has lately been understood also in the design of tools and systems for professional use in industrial environments (see e.g., Kaasinen et al., 2015). In professional usage, a good user experience means, for example, that the tool supports the user's skills and enables experiences of success while conducting one's work tasks. Therefore, the user can feel to be in control of one's work and tools.

In the FIMECC UXUS (User Experience and Usability in Complex Systems) research program, we designed and evaluated a novel concept for a remote operator station (ROS) for container cranes (see Figure 1) by taking user experience as a focal point in the development. The design of the ROS was based on field user studies conducted in international ports (for details, see e.g., Karvonen, Koskinen & Haggrén, 2011). The aim of these studies was to familiarize ourselves with the work and working environment of the crane operators and to conduct a core-task analysis of their work.

Figure 1. The Remote Operator Station, © Konecranes

In the beginning of the design, we identified several possible UX goals (Kaasinen et al., 2015) based on the core-task analysis (see e.g., Norros, Savioja & Koskinen, 2015) of the conducted field studies and the Systems Usability Framework (Savioja & Norros, 2013). Out of these goals, we finally chose the following four experiential goals for the ROS design: 1) feeling of safe operation, 2) sense of control, 3) feeling of presence, and 4) experience of fluent co-operation. Out of these UX goals, for example, feeling of presence is important in remote operation, because the operator has to understand the prevailing conditions in the container loading zone with sufficient level of realism although not being present on the spot. The above-mentioned four UX goals have been presented in more detail in Koskinen, Karvonen & Tokkonen (2012) and Kaasinen et al., (2015). For the design work, we also defined the overall UX vision for the ROS to be 'Hands-on experience in remote operation' to which all the finally chosen UX goals were seen to contribute to.

We also defined user requirements, which were connected to the chosen UX goals. For example, we defined a requirement 'The provided operation views present the loading zone in an integrated and consistent way', which was connected to the 'Feeling of presence' UX goal. Furthermore, for the defined UX goals we made concrete design implications, which described how the goals should be interpreted in this particular context. For example, the design implications related to 'Feeling of presence' UX goal were related to supporting the understanding of physical dimensions of the loading zone, quality of interaction (e.g., feel of operation and clarity of the operating view), and presenting information from the loading zone without delays. In this way, it was possible to create a solid basis for the concept design in co-design workshops.

When designing the final concept, we also were involved in defining a virtual reality based prototype system of the remote operator station (see Figure 2). The prototype was evaluated in different phases of development with users (see e.g., Karvonen et al., 2014). In these evaluations, the fulfilment of the defined UX goals was evaluated when the design work progressed. This evaluation process involved the comparison of user requirements and UX goals against the results of the user tests by utilizing the Usability Case method (for details, see Karvonen et al., 2014).

Figure 2. Concept illustration of the ROS, © Konecranes

According to the crane manufacturer's Design Manager Johannes Tarkiainen, the resulting concept is 'innovative and at the same time practical'. Furthermore, it was described to 'follow the identified user needs' and 'a perfect fit for the planned operational environment'. We see that these achievements were due to the human factors and UX goals work during the design process. The final product was taken into use in a large port automation project by the crane manufacturer.

CONCLUSIONS ABOUT HUMAN FACTORS ISSUES RELATED TO REMOTE OPERATION

Based on the ROS design case, we conclude by presenting some general human factors issues that we see need to be considered when designing RO systems. First of all, visibility issues may arise with RO solutions, as the remote operator is not on-the-spot observing the situation; the operator has to use limited camera views to see to the operation environment. The video camera feeds usually present only 2D video, which cannot mediate comprehensively the depth perceptions and dimensions of the object environment. Therefore, a stereoscopic view is not made possible for the operator. However, the depth perception could be supported, for example, with augmented reality (AR) visualisations on top of the video feed (e.g., AR lines with distances presented next to them).

Second, feedback through other modalities than vision also deteriorates. For example, auditory feedback in operation is often very important, yet unconscious part of safe work. Therefore, in RO solutions, it is important to think what sounds from the object environment should be heard and delivered to the remote operator and how. Also, haptic user interfaces could be utilized to support the sense of feeling from the operating forces or the movements of the teleoperated machine.

Third, we can state that although it is beneficial to have high-quality data (like high-resolution video feeds) from the object environment, it should not compromise the system's responsiveness. Even the smallest delay in the video feed may have a detrimental effect on conducting work tasks with an RO user interface. This problem is especially common in RO applications where distance from the operation user interface to the object environment is long. We see that the usage of AR to highlight important details from the camera views could be a solution instead of video resolution increases.

Finally, RO may be taken as an intermediate stage towards autonomous machines conducting work tasks without direct remote manipulation. When the level of autonomy increases, more emphasis in the operator's work will be placed on monitoring the object environment and handling exception situation. This kind of a situation may bring several challenges (Bainbridge, 1983). For example, skills needed in special situations are hard to maintain and develop if RO is conducted only rarely in exception cases. On the other hand, maintaining vigilance can be hard if not much is happening when the operator is monitoring the system. The exception situations are complex and rather than alarms the operator would need well-analysed data to support situation awareness. Preferably, the data should be predictive so that it helps in preventing exception situations rather than just having the operators react to them. Furthermore, it may be challenging to recruit competent workforce for monitoring work although good professional skills and knowledge would be necessary. RO work and worker roles should be designed so that they are an attractive option for skilful professionals.

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18. STUDY OF THE AIRCRAFT ENVIRONMENTAL CONTROL SYSTEMS DYNAMIC RESPONSE USING MODEL-BASED APPROACH

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ABSTRACT

An environmental control system (ECS) creates habitable living conditions inside an aircraft by pressurizing the cabin, controlling temperature and providing breathing air. This has a major impact on a crew's comfort, performance and safety. The objective of this project was to develop a semi-empirical simulation model of an aircraft's ECS in order to study ECS's dynamic response. By understanding the transient phenomena most problematic characteristics of the system can be understood and possibly eliminated. The project resulted in a partially verified simulation model which is valid in some of the most common flight situations. The complete simulation model provides deep understanding of systems characteristics and explains why the system reacts to transient changes in a particular way. Gathered knowledge can and will be utilized in the future research related to ECS.

INTRODUCTION

Creating habitable living conditions inside an aircraft is a very complex task. In this particular aircraft seven valves are required to modulate the mass flow at all times. Failure of even one of these valves causes problems which can be seen in a form of pressure, temperature or mass flow fluctuation. It is almost impossible to predict the outcomes of such failures without physical tests with aircraft or with simulations.

Simulations can be run with physical replica (test rig) or model-based computer model. In this project the only sensible way to gather understanding of the system was with a semi-empirical simulation model. Test rigs would have been slow to implement and susceptible for errors when a high altitude flight is considered. All in all, aircrafts ECS was known to be the most problematic at high altitudes and computer simulation provided the best way of studying the cause.

METHODOLOGY

The semi-empirical simulation model was constructed by using all the available knowledge. Some of the data from the aircrafts design process was available, which provided precise knowledge of the cooling flow amount (ram air), air cycle machine characteristics, heat exchangers cooling effectiveness, valve construction and heat stress created by the equipment. Also, aircrafts were tested on the ground which gave the knowledge of the pressure levels inside the ECS during ground operation. In addition, valves movements were videotaped during ground operation and some of the valves were also tested in a test bench. Lastly, systems working principle was studied from the aircraft manual which gave the knowledge of the target mass flow amounts, target pressure levels and permissible temperatures during the operation.

The actual simulation model was constructed by using LMS Imagine.Lab Amesim (rev. 13). Simulation model takes into consideration working of control systems, heat exchange, pressure losses, air cycle machine, ram air, jet engines and changing properties of ambient air. The model was verified with all the available data and can be considered valid in most of the typical flight situations.

The most challenging task was to validate simulation models accuracy at high altitude flight situations. High altitude operation cannot be verified directly as the measurements inside the ECS are impossible during flight. However, pressure and temperature in the cabin can be measured throughout the flight and the simulation results are easily compared to these measurements. If the simulation model results and the measured values match, it can be concluded that simulation gives fairly accurate results.

All the simulation cases represent real flight situations. Data from the flight recorder can be used as an input to the simulation model so that simulation results are comparable with measurements. Following variables from flight recorder are used as input: ECS supply pressure, ambient air pressure, ambient temperature, aircraft velocity and altitude.

RESULTS & DISCUSSION

Primary target was to study systems behavior near aircrafts service ceiling at 45,000 feet altitude as the ECS is known to be most unstable at high altitudes. In addition to unfavorable altitude, also the throttle was altered rapidly in order to create large pressure fluctuation to the ECS supply pressure (bleed air pressure). The supply pressure fluctuated between 2.5 to 6.3 bar. High altitude and throttle alternation together created the most unstable situation in which ECS can possibly operate.

Figure 1 shows difference between simulated and measured cabin pressure values. As can be seen, simulated cabin pressure values react same way to the plummeting supply pressure. However, when supply pressure rises simulation models behavior is more sedate. Amplitudes of the pressure fluctuation are almost identical.

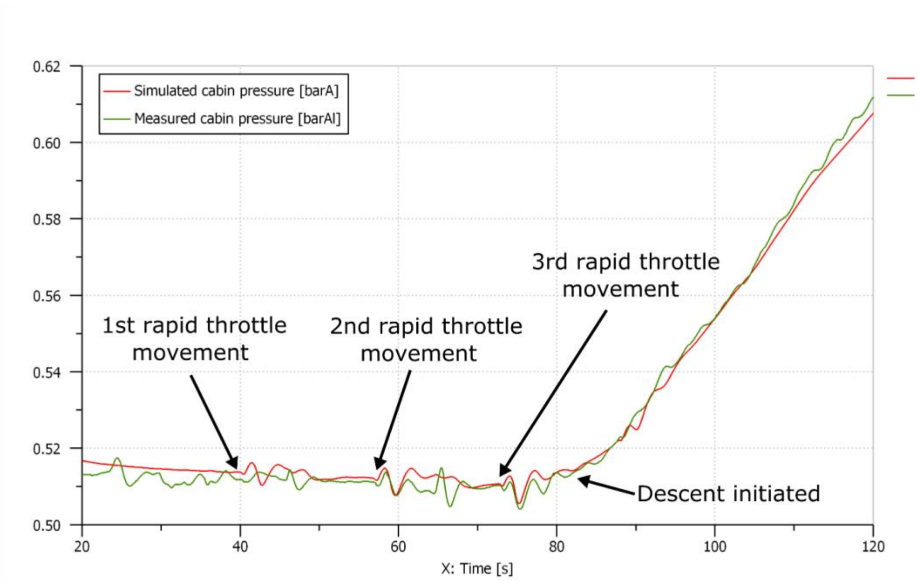

Figure 4. Cabin pressure at 45,000 feet altitude during rapid throttle alteration

Figure 2 shows the movement of the most influential valves. Mainly these valves cause the pressure fluctuation shown in figure 1. All valve positions are simulated and real valve positions cannot be measured nor observed during flight. These results give valuable knowledge of system response to the transient changes.

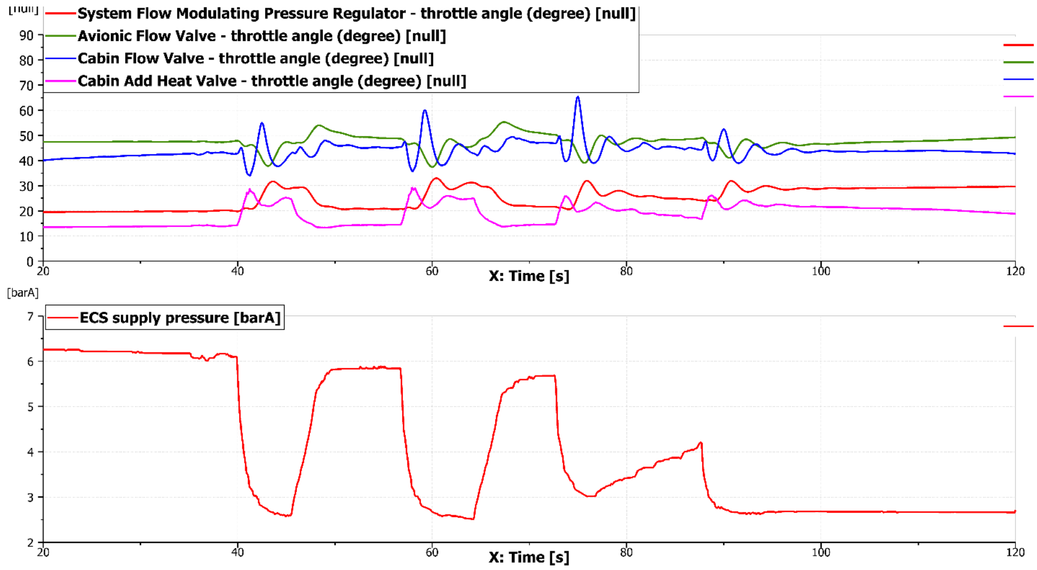

Figure 5. Valve movement during rapid throttle alternation at 45,000 feet altitude and ECS supply pressure

Every single valve only tries to control one quantity (mass flow, pressure or temperature). Together these valves create the habitable conditions to the cabin. Basically, these valves sort of dance with each other in a way that creates distinctive pressure fluctuation to the cabin. Process in itself is so complicated that simulations and measurements do not match up just by chance.

CONCLUSION

- Simulation model makes it possible to study underlying phenomena leading to pressure fluctuation.
- Results are promising and can be utilized in future researches
- Simulation model can be utilized to some specific fault diagnosis or troubleshooting
- Model has its limitations and it can be utilized reliably only to some flight situations

19. MODELING AND PRELIMINARY DESIGN OF UNDERWATER ROBOT FOR INSPECTION

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ABSTRACT

By advancing robotic perception technology, the development of Autonomous Underwater Vehicles caught attention in certain application such as oceanology and surveying. This paper proposes an innovative approach for the design of a highly maneuverable underwater robot with 4 degrees of freedom. The mission of the aforementioned AUV is to inspect the inaccessible flooded mines and collect geological data during 5 hours of operation. Following, the configuration and mechanical design of the thrusters and pendulum mechanism are outlined. Further, low-level control architecture for real-time operating of eight thrusters is presented. Besides, dynamic modelling of the system, hydrodynamic terms and transformation matrix based on Euler angle are identified.

Keywords—Underwater robot, Motion control, ROV design

INTRODUCTION

During recent years the design of Remotely Operated Underwater Vehicle (ROV) is extended significantly, particularly ROVs which are inspired by underwater species such as [1]. Furthermore, Autonomous Underwater Vehicle (AUV) are more advanced in terms of navigation, perception and power consumption [2] .

the project UNEXMIN investigates to utilize the capabilities of the fully autonomous sea robot to prospect flooded mines, where technological challenges hindered human accessibility to mine for years. UNEXMIN ”Autonomous Underwater Explorer for Flooded Mines” aim to deliver valuable graphical and geological information. Following , describes the design of the platform, propulsion system, buoyancy and etc. that have been used in the robot. Note that the mechatronic architecturing unit and navigation is out of the scope of this paper.

SPHERICAL DESIGN

To achieve a decent design, a number of factors must be taken into account during the development phase. A streamlined outer shape is critical for sufficient efficiency, particularly where a number of components such as vision sensors, instrumentation and thrusters will be assembled over the robot structure. Moreover maneuverability of the robot is required in order to pass through narrow spaces. After a number of trials, a sphere shape structure is chosen as the main platform. This sphere consider as close frame pressure hull to include all the components inside. The sphere is water tight (60 bar) and it consists of upper and lower semi sphere with the thickness of 7 mm aluminum. According to table 1, the weight of the robot is 106 kg and the diameter is 60 cm.

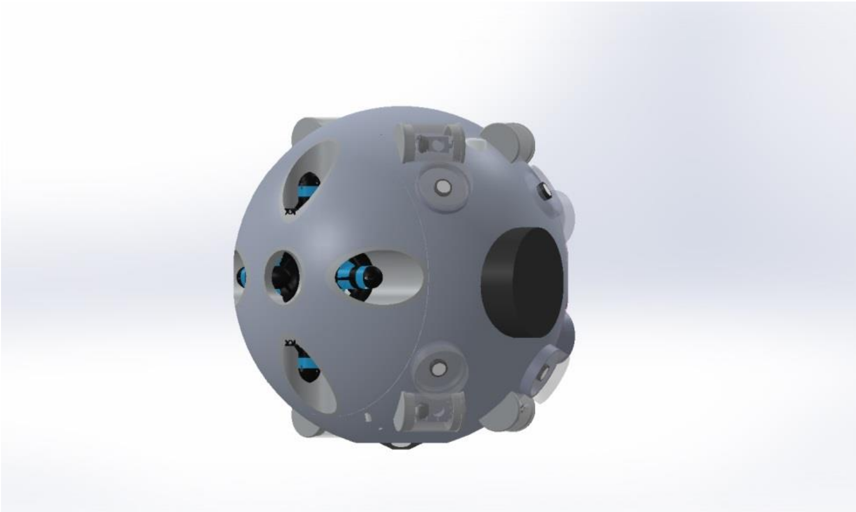

Figure 6: Robot CAD design

The characteristic of the environment that the robot need to be driven indicate a certain degree of freedoms. Complete horizontal and vertical motion is a necessity in this application. Hence, as it will be explained in section ‘propulsion unit’, a propulsion system consists of several thrusters covered surge, heave and heading control of the robot. On the other hand, the robot is equipped with ballast control for vertically long displacement. Furthermore, the advantage of utilizing a pendulum system for pitch angle is described later in the following section briefly [3].

The robot is also equipped with 6 cameras and 6 laser scanners for the navigation, the configuration of 4 cameras and a laser scanners in bow and 2 cameras and s laser scanner in stern provide a sufficient observation angle to control the robot autonomously. Moreover, the robot is advanced with multibeam sonar, inertia navigation sensor and laser beam.

Table 1 Robot specification

Parameters	
Weight	***106***
Size ø	***0.6 m***
Velocity	***0.5 m/s***
DOF	***5***
Operating depth	***500 m***
Number of thrusters	***8***

PROPULSION UNIT

As it is described in the introduction, The robot has 8 thrusters which are distributed on port and starboard side inside a cross-shaped manifold symmetrically. To be precise, there are 4 thrusters in each side, two in horizontal and two in vertical orientation. Therefore, the 4 horizontal thrusters configuration can contribute to surge and heading control motion. On the other hand, the 4 vertical thrusters provide heave motion when the robot position need to be accurately control alongside the shafts or galleries. Note that off the center (CG) location of the vertical thruster can also provide roll motion, however this degree of freedom won't be actively controlled.

Each thruster is a 12 volt brushless motor about 350 g dry weight, which comes with a speed controller with CAN protocol communication. Maximum power produced by each thruster would be 350 watts.

BUOYANCY CONTROL

Having a buoyancy system for AUV operating in deep sea is quite common in view of the fact that, it lowers the amount of energy consumption in compare with thrusters. In this context, controlling the velocity of the robot over a certain vertical path can effect on energy consumption reduction.

The buoyancy control in our application is about changing the volume of the sphere only when the robot follows the long vertical path. In this design, the variable volume is about 4 liters, while the transformer oil will be pumped from the reservior to the bladder in order to minimize or maximize the buoyancy effect. The pump is controlled via a brushless motor which has the same speed controller as the thrusters. About 80% percent of the bladder is full, while the robot is overlapping with the water surface (the initial position of the robot inside the water). As the robot increase the depth from the water surface, the volume of bladder drops which simultaneously effect on the stability of the robot.

PENDULUM MECHANISM

Primary, the idea of rotating a mass around the center of the gravity of the robot is developed in order to pitch and maintain the robot in certain angle independent from te propulsion system. Hence the pitch control can be implemented simultaneously during surge or heave or individually on a spot. This method also yields wider angle for a navigation system such as multibeam sonar.

The weight of 3 batteries (6kg) over a supporting structure is used to build a pendulum structure with the radius of 7.5 cm from the center, which is correspond to center of volume; and a stepper motor drives the mechansim through a gear.

Note that converging the center of gravity and center of volume is a keystone through out the whole design process, owing to the fact that it directly affects on robot instability. That being said, the vatiable buoyancy control and pitch angle always alter the robot stability. Hence, maintaining the center of gravity the lower than center of gravity is always critical.

CONCLUSION

The paper addresses an innovative design layout for an underwater robotic platform which can be utilized for inspection, navigation and collecting geological data. As stated above, the sphere structure is modeled and propulsion system, buoyancy and pendulum mechanism are under development. Concurrently, Low-level control is in progress which will be extended to the high level of control, where the certain path can be followed by the robot in order to stabilize the dynamic equation of motion.

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20. AUGMENTED REALITY DIESEL ENGINE NOISE

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ABSTRACT

There is a need to present machinery simulation and measurement results in more advanced ways than conventional report or slide set format. Also, some degree of interactivity is desirable. A method to achieve this is to utilise Augmented Reality (AR) environments, combining vision and sound in an interactive manner. To demonstrate this approach, an AR diesel engine model was developed. The 3D AR model was enhanced with the audible model to evaluate the sound of a diesel engine at different locations. With the AR model a 3D image of the engine may be virtually located in any environment and observed through a tablet computer. The augmented reality model suits well for presenting simulation and measurement results. Additionally, it may be used in product development for what-if scenarios.

INTRODUCTION

There is a need to present machinery simulation and measurement results in more advanced ways than conventional report or slide set format. Particularly the noise simulations and measurements would benefit from more advanced presentation methods. Especially, when some interactive design work is carried out improved presentation methods are preferred. They include the full utilisation of the vision and sound. A way to accomplish this includes Augmented Reality (AR) environments (1-4). A diagram of such a system targeted for the noise-related presentations is shown in Fig. 1.

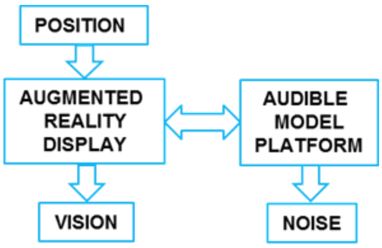

Fig. 1. The structure of the demonstration system.

METHODS

An AR environment together with a sound synthesis was utilised. The 3D AR model was enhanced with the audible model to evaluate the sound of a diesel engine at different locations. The environment consisted of a table computer running the AR application. It was attached wirelessly to a laptop computer running the sound synthesis system. The AR environment was created with 3D AR software (5). The 3D model was tracked against a key figure by a specific tracker software (6).

The engine sound was synthesised with an engine audible, real-time model. That model used Audible Model Platform (AMP), which has been utilised in several similar applications earlier (7,1), To get the data for the audible model, a four-stroke turbo charged diesel engine (AGCO

Power 44 AWIC) was acoustically characterised in 4 different methods in a semianechoic laboratory, as shown in Table 1. The noise parameters were extracted by the method 4, and utilised in AMP. Other methods, especially the method 3, was utilised to create the visual image of the sound field.

Table 1. The acoustical characterisation methods.

Method	Purpose
1. Sound pressure method	Sound power determination
2. Sound intensity method	Sound power determination, sound intensity map
3. Sound pressure and particle velocity method	Sound power determination, surface vibration map, sound intensity map
4. Sound time series acquisition around engine	Audible model parameter extraction

RESULTS

The noise parameters we successfully converted for the AMP format and engine noise simulator was created (shown in Fig. 2). For the AR application engine 3D CAD model was used. Also a photograph-based 3D model was tested, but due to the large amount of details it was found to be too complex.

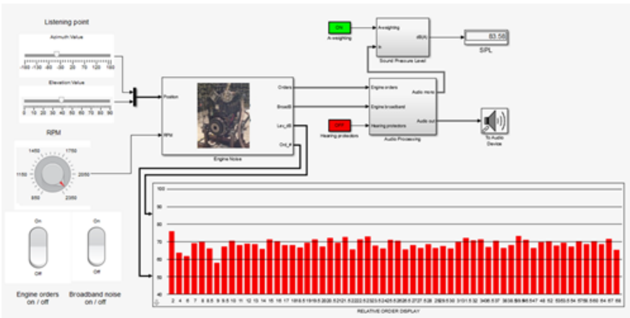

Fig. 2. Audible Model Platform (AMP) adapted to the simulated diesel engine sound application.

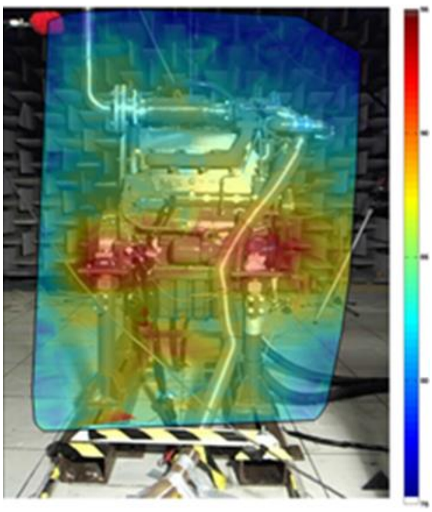

Fig. 3. The engine in the lab with overlaid sound particle velocity map.

The noise maps (Fig. 3) were used only as 2D versions, but the work is in progress to convert them to full 3D visualisations. The practical application was able to track the engine location, transfer data to the AMP, and reproduce the engine sound at different locations and RPMs. Both models operated concurrently and exchanged parametric data in real time.

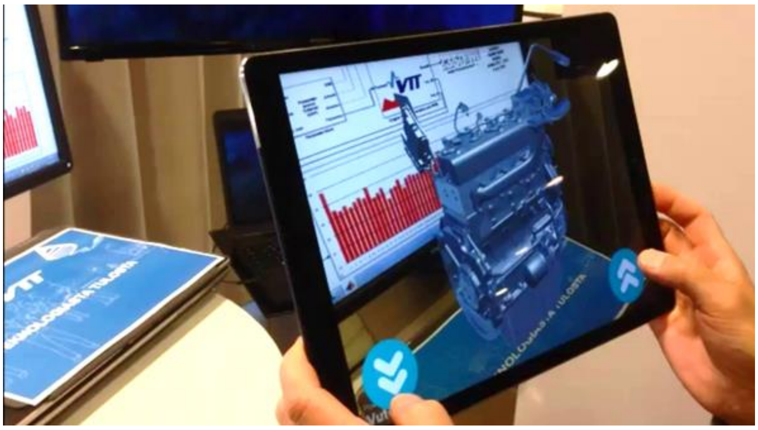

Fig. 4. The engine application running in the tablet PC.

CONCLUSIONS

With the Augmented Reality (AR) model a 3D image of the engine may be virtually located in any environment and observed through a tablet computer, including both sound and visions. The AR model suits well for presenting simulation and measurement results. Additionally, it may be used in product development for what-if scenarios. The audible model parameters may be modified on-the-fly and various scenarios may be assessed, to enrich the product development.

ACKNOWLEDGEMENTS

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IV Digital Design and Product Development

21. LOW-FIDELITY DESIGN ANALYSIS TOOL FOR EARLY DESIGN PHASE

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ABSTACT

This paper presents concept of low-fidelity modelling of system properties with a Design Analysis (DA) tool. Furthermore, time, effort and modelling error is considered compared to high-fidelity modelling in the case of design of a pneumatic motion platform. The idea in low-fidelity modelling is to create simplified equations between design parameters and system characteristics using heuristic reasoning.

INTRODUCTION

Conceptual design phase is the most important phase in Product Development Project (PDP) because most important decisions on design are fixed in this phase. Unfortunately, this phase is not well supported by simulation tools due to tight schedule of PDP. It is a common observation in industry that high-fidelity models, such as Simulink models, do not fit well on tight time-frame of the PDP-project.

One solution for this is to use low-fidelity modeling and efficient DA-tool. This paper presents the DA-tool and an example on using it for design of a pneumatic motion platform. The DA-tool is made in TUT/MEI. The DA-tool generates sensitivity analysis of design parameters, correlation analysis of product properties and optimization of design parameters within given limits. This information gives explicit insight on possibilities and restrictions in design. A low-fidelity model between design parameters and product characteristics can be programmed either in Excel or in Matlab.

LOW-FIDELITY DESIGN ANALYSIS TOOL

The design analysis tool was implemented in Excel, which is widely used in early design calculations, providing useful tables for displaying relationships between design parameters and system characteristics. The DA-tool has a field for design parameters and a field for system characteristics. The user interface of the DA-tool is shown in Figure 1. Changing of a parameter results in new values for system characteristics. Activation of calculation buttons results in parameter sensitivity analysis and system characteristics correlation analysis respectively. In optimization function (yellow field) one can set target values for system characteristics and minimum and maximum values for parameters values. The DA-tool use Excel optimization algorithm for this operation.

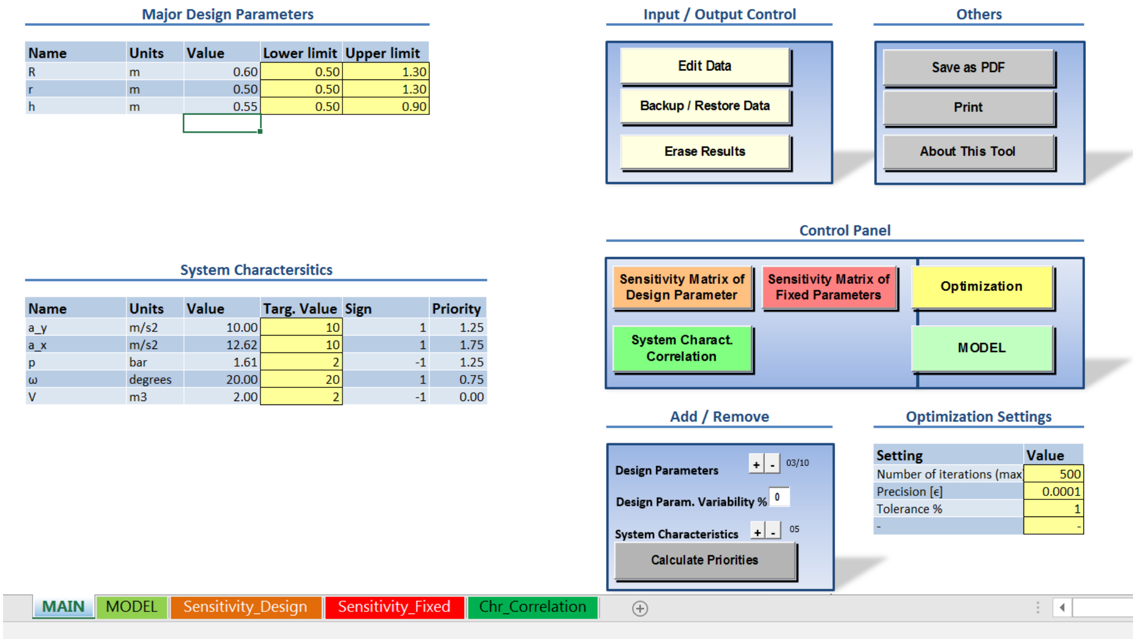

Figure 1. User Interface of the Design Analysis tool.

Relative sensitivity matrix of design variables and system characteristics correlation tables are presented in figure 2. Relative sensitivity matrix, explained more detail in [1] and [2] map together system characteristics (in rows) and design parameters (in columns). It can be seen, that the first parameter R (1. column) has only small effect on system characteristic in this operation point. Parameter r (2. column) has more influence. Increasing it by 1 % would result in 0.44 % loss in system characteristic a_y (1. row) and 0.44 increase in a_x (2. row) etc. From system characteristics correlation table it can be seen that characteristics a_y and a_x are completely opposite characteristic. Therefore improving characteristic a_y (vertical acceleration) would impair characteristic a_x (horizontal acceleration) in design example.

Relative Sensitivity Matrix of the Design Parameters

			R	r	h
			m	m	m
		Actual value	0.50	0.78	0.52
a_y	m/s2	9.97	-0.06	-0.44	0.50
a_x	m/s2	12.62	0.06	0.44	-0.50
p	bar	1.61	0.06	0.44	-0.50
ω	degrees	20.00	0.03	0.47	-0.50
V	m3	1.01	0.00	0.67	0.33
			0.27	2.23	2.50

(*)System Design Parameter Priorities

Adjusted System Characteristics Correlation Table (ASCC)

			a_y	a_x	p	ω	V
			m/s2	m/s2	bar	degrees	m3
		Actual value	9.97	12.62	1.61	20.00	1.01
a_y	m/s2	9.97	1.00	-1.00	1.00	-1.00	0.26
a_x	m/s2	12.62		1.00	-1.00	1.00	-0.26
p	bar	1.61			1.00	-1.00	0.26
ω	degrees	20.00				1.00	-0.28
V	m3	1.01					1.00

Figure 2. Relative sensitivity matrix of design variables (left) and system characteristics correlation table (right).

DESIGN EXAMPLE

Design example used in this study is a pneumatic motion platform shown in the figure 3. It is used in virtual environment in order to increase immersion in virtual verification of cockpit model for mobile machines. The mobile platform is actuated by six pneumatic muscle actuators. They are joined to pylons of the base structure and to corners of the moving platform. Design of the platform can be described by three design parameters:

R = diameter of joints in moving platform

r = diameter of joints in base structure

h = height of joints in base structure

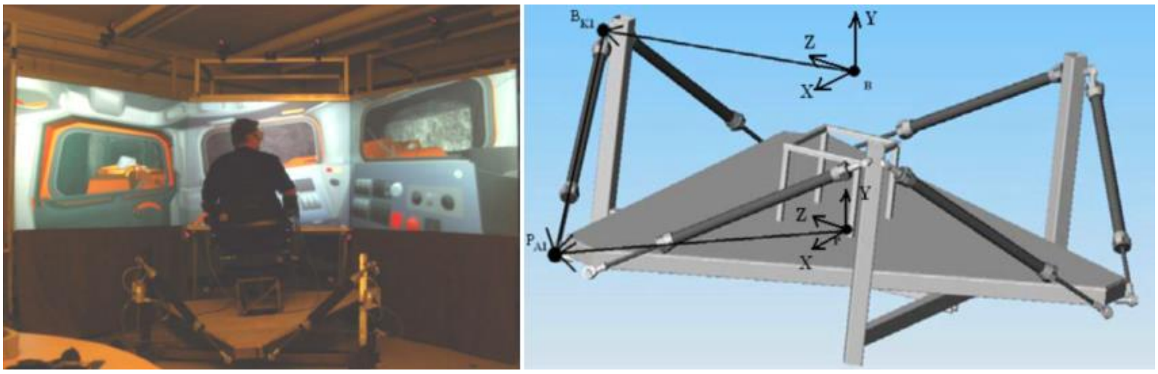

Figure 3. Design example. A Pneumatic motion platform

Main systems characteristics are:

a_y and a_x = vertical and horizontal acceleration of the platform

p = mean pneumatic pressure

ω = maximum inclination of the platform

V = volume of the platform

The system model needs to be explicit model between design parameters and system characteristics. In this case the model consists of three equations of steady state force balance in low, medium and high level positions of the motion platform [2].

The modeling effort of this design problem with high-fidelity modeling (Simulink) approach was studied as an alternative. Both low- and high-fidelity modeling approaches are compared in Table 1. It presents number of equations that need to be programmed, the number of parameters that need to be identified, the time required to create the model, and the time needed for analyzing the model. In this study, the modeler had a good knowledge of the simulation tools and technologies used.

	Low-fidelity model	High-fidelity model
Number of model equations	14	30 eqs. + 58 SimMech. blocks
Number of model parameters	10	270
Time required for creation the model [h]	7	120
Time required for analyzing the model [h]	1	16
Expertise needed in modeling	Low	High

CONCLUSIONS

In this paper, low-fidelity modeling with the DA-tool was studied in a practical design case of a portable motion platform. The information of the low-fidelity model can be significantly extracted by the DA-tool, which makes it fast and easy to analyze system characteristics.

For comparison, a high-fidelity modeling approach was realized using Matlab/Simulink/ SimMechanics toolboxes. The modeling approaches were evaluated and compared by the number of equations needed to be programmed, the number of parameters needed to be identified, time required to create the model, time needed for analyzing the model, and the accuracy of the model. The results indicate that the high-fidelity approach is capable of providing a very accurate model (relative error 4–6 %) at the cost of time (136 h) used for identifying the system parameters, analyzing and creating the model. As such, the high-fidelity model is very useful in a detailed design process phase, providing e.g. the validation and verification of design solutions by simulations. In this example case, the low-fidelity model was achieved within one day with a reasonably small number of equations and parameters. The relative error of low-fidelity approach was about 21–25 per cent, which is reasonable for use in the early stage in design process. Both the low-fidelity and the high-fidelity modeling approaches are justified because more accurate knowledge is needed in detailed design of the system.

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22. VIRTUAL COLLABORATION FOR SUSTAINABLE UPGRADE INNOVATION

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ABSTRACT

Competitive markets with changing demand, fast moving market entrants and a continuous stream of new, enabling technologies poses specific challenges to well established industries supplying high-investment products with long life-cycles. To meet changing requirements, systems that cannot easily be replaced, need to be continually upgraded to add new features, improve efficiency or to ensure an economically and environmentally sustainable, extend service life. Providing successful and sustainable system upgrades requires a comprehensive approach. Tools and processes for enhanced adaptation agility through a continuous upgrade innovation strategy have been developed as part of the EU funded research project Use-it-Wisely. The approach is based on extensive actor involvement and virtual collaboration across the value network throughout project life. The solutions have been developed and tested in six different industrial clusters, demonstrating the general applicability of the results. Collaboration between previously unconnected sectors has emerged as one of the main benefits of the project. In addition to individual applications a virtual platform for collaborative creation and sharing of resources dedicated to sustainable development of high-investment product-services will be established. The paper presents the significant outcomes of the project and discusses potential future development.

INTRODUCTION

The current trend of increasingly personalised products and services has strained mass production processes and forced industries to find new ways to produce and deliver goods to meet changing market demands. In general, the demand for an increased variety of solutions leads to smaller production series and shorter system life-cycles. At the same time, requirements for reduced ecological footprint and reduced total cost of ownership call for an opposite development (EFFRA, 2013). In many cases, frequent recommissioning of equipment causes significant investments and disturbances to operation. New systems may also induce compatibility issues with legacy system components, resulting in unpredicted consequences. Especially for low-volume and high-investment systems, extending operational life-cycles through gradual, carefully designed upgrade interventions appear as a more viable alternative.

The challenge of meeting changing requirements while at the same time extending operational life-cycles can be solved through software functionalities, which can sustain high frequency of renewal, or by the design of products, processes and systems that allow the sustainable re-manufacturing and materials recycling (EFFRA, 2013).

To compete successfully organisations, need to increase their innovative capability. Extending the innovation process to include a wider audience is one way of approaching this challenge (Bessant & Caffyn, 1997). This is known from the philosophy of Kaizen, where employees are extensively involved in a continuous improvement process based on sustained problem solving (Imai, 1996). However, in the increasingly networked business environment extending innovation activities not only outside R&D departments but also beyond corporate borders becomes paramount (Lakhani, Lifshitz - Assaf, & Tushman, 2012). Increased collaboration is also one of the key elements of Industry 4.0.

In July 2013 twenty organisations representing research and industry across Europe signed an agreement with the European Commission to undertake a research project focusing on upgrading of capital intensive product-services. The project called "Innovative continuous upgrades of high investment product-services", short-named "Use-it-Wisely", was funded under the European Commission's seventh Framework Programme as part of the Factories of the Future public-private partnership. The objective of the project was to investigate new business models, tools and practices to support continuous adaptation to changing demands through sequences of innovative upgrade increments based on extensive actor involvement.

RESEARCH SETTING

The research focus was the transition from a linear product delivery process to an integrated, continuous process of small-step incremental upgrade innovations based on collaboration within value chains, across industry sectors, and between research and practice. The target areas selected for the research were: business modelling; virtual collaboration techniques; and model-based systems engineering approaches.

The project work was formed around six separate pilot cases, representing six different industries: energy production, heavy machinery, aerospace, automotive, ship building and office furniture. The pilot cases included specific research targets including maintenance inspection, upgrade service development, model-based systems engineering, and circular economy. Instead of focusing on individual technological solutions of individual use cases a range of generic approaches were adopted and tried across the six pilots. The goal was to apply a holistic approach in order to discover latent mechanisms and causal dependencies that could affect the outcome of introduced change, and eventually the success of suggested upgrades. The broad range of viewpoints covered by the research enabled a wider range of actors to participate in the collaboration, such as design engineers, service personnel, sales staff, decision makers and end users. The different pilot cases forced to focus on challenges common across industries and provided a basis for demonstrating general applicability of the results.

METHODOLOGY

The research followed an iterative approach. In the first stage the six use cases were analysed to identify specific challenges and business opportunities and to extract commonalities. Rich pictures were used to facilitate communication between actors on different levels and to create a shared view of the target case. Business perspectives were analysed using system dynamics (SD) modelling to be able to identify influence factors and causal relationships. In successive iterations analysis was refined and tools for further enhancing collaboration and data management were developed. Virtual and augmented reality techniques were selected to develop collaboration applications facilitating communication between various actors. A shared platform comprising of tools and resources was established. The final stage included a sequence of on-site demonstrations of the pilot cases.

ACADEMIC AND PRACTICAL OUTCOMES

The project contributed to a managed transition from a linear product delivery process to an integrated, continuous process in the participating organisations. The broad scope of the study allowed for applications supporting both a horizontal integration (through the life-cycle) and vertical integration ("shop-floor to top-floor"). In addition, the collaboration between research and practice as well as between seemingly unrelated industries proved beneficial and provided new viewpoints to identified problems. This observation is in line with previous research supporting the hypothesis that good ideas emerges from the intersection of diverse social worlds, across "structural holes" in knowledge networks (Burt, 2011).

One of the barriers to creativity was found to be the influence of preconceptions limiting the potential range of innovative thinking (Fox, 2013). A set of tools was developed to support creative thinking and to break preconceptions (Fox, 2016), (Fox & Vahala, 2016a). In addition to this, a symbol system for strategic design of production systems was produced (Fox & Vahala, 2016b). The tools have been tested in several institutions outside of the project consortium, including Cranfield University, UK; Aalto University Finland – being used in Spain and Mexico; I4MS EU – UK; European Space Agency; and the MIT Technology Policy Program, US.

The practical outcomes comprised sets of tools and methodologies defining a generic framework covering three main categories: 1) business analysis; 2) collaboration technologies; and 3) systems engineering.

Examples of individual, case-specific outcomes include:

- A web-based Virtual Reality application for managing and communicating inspection results between service engineers and designers,
- Augmented Reality application for mobile devices for visualizing upgrade designs field conditions.
- Set of tools and methods for photogrammetric 3D scanning of upgrade targets using mobile equipment,
- Expert tool merging 3D scanned point clouds with CAD models for enhanced communication between actors,
- A model-based Systems Engineering toolchain combining modelling, networks, data semantics and multidisciplinary collaborative environments,
- Tools and methodologies to address issues in the whole life-cycle of a passenger boat, from customer requirements to design, manufacturing and updating.
- A life-cycle assessment tool for circular economy
- Identification of exploitable results and business case development.

As a project-wide result a web-based knowledge sharing environment was implemented for sharing of resources and expertise to facilitate innovation and creativity in participating organizations and to support the life-long, sustainable adaption of high investment product-service.

IMPACT

The project developed prototype solutions and produced factory floor demonstrations. As the results were not implemented in operational settings, it was not possible to measure quantitative impact. However, some indications can be given. Expected impact include: Increased collaboration and enhanced communication between actor groups; reduction of time and cost related to decision making, designing, manufacturing and updating; reduction in environmental impact through adopting circular economy principles; and progress in the transition towards model-based systems engineering approaches.

RELIABILITY AND TRANSFERABILITY

The individual applications were verified in laboratory tests and validated in factory floor demonstrations based on collected feedback from relevant actors. The involvement of several diverse industries serve to prove the transferability of the results.

CONCLUSIONS

Tools and methods supporting the life-long adaptation of high-investment product-services were tested and developed in six different industry networks. The comprehensive approach comprising business analysis, collaboration and design data management resulted in a generic framework approach applicable across industries. The approach builds on the combined knowledge of relevant actor networks and a collaborative way of working. A platform for distributing and the results and resources of the project was established. Further development of the approach will be continued in an open virtual community of practice.

ACKNOWLEDGEMENTS

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The results build on the combined efforts of the twenty organisation participating in the Use-it-Wisely project.

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23. AUTOMATIC SIMULATION PLATFORM TO SUPPORT PRODUCT DESIGN

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ABSTRACT

In product design and development there is an ever increasing need for better and reliable products. The design process should be fast and cost effective. Computational power is increasing and at the same time the hardware costs are decreasing. The variety of commercial as well as open source simulation software is huge. Additionally, easy to use and learn scripting languages are more and more becoming an important part of the whole analysis process. To support the whole product design process, effective software independent tools are needed. Automated analysis processes are needed when seeking optimal solutions via optimization or parameter variation. These increases also reliability by avoidance of human errors. With the automated processes the visualization and documentation of the results is easy. Modern and flexible software combined with effective hardware and connected together with effective scripting languages makes it possible to develop wholly automatic and reliable calculation processes. These processes can then be combined with optimization loops thus enabling product optimization and control of the inevitable uncertainty in model parameters. As a test case, the automatic analysis system presented in this study is applied to optimization of vibratory behaviour of a diesel-generator set.

INTRODUCTION

Automation of analysis processes is the key if one wants to meet the demanding requirements in product design and at the same time, wants to take computational possibilities into effective use. The increase in the computational power makes it also possible to take advantage of the numerous optimization methods. Existing analysis software and scripting languages offer great possibilities to develop an automatic simulation system. They can be directly incorporated into optimization algorithms thus providing an effective tool in designing better products or in the development of entirely new product families. In fact, the automating of computational work is a fundamental factor in the effective utilization of optimization methods. The advantages of structural analysis automation and its incorporation in optimization and parameter variation algorithms are many. These can be for example analysis time reduction and cost savings, automation of standardized calculations, reliability due to avoidance of human errors, multi-physical solutions via linking of e.g. thermal, stress and fatigue, noise and vibration analyses, repeatability and modularity in analysis process and automatic documentation and reporting of results. In product design the designer can increase understanding of the relations between input and output variables with the help of sensitivity studies and statistical analysis using computer experiments.

Although modern optimization methods are becoming more and more common in industry there is still a need to make the use of these methods more effective. An important requirement in making sophisticated optimization methods useful is to enable modification of calculation models straightforward without any user interaction. Moreover, effective hardware environment can help the industry to take these methods in effective use in their product design and problem solving. The automatic calculation engine is a key requirement in using optimization systems.

AUTOMATIC ANALYSIS SYSTEM IN OPTIMIZATION

In order to use optimization effectively in product design, the analysis system must fulfil certain requirements. The analysis system should be computationally effective and adjustable for different analysis needs. It should perform the model and parameter pre-processing, analysis and fetching the required results. This kind of analysis system or calculation engine should be such that it can be used either as a stand-alone calculation robot or it can be incorporated into a separate optimization or other software to manage the calculation cases. Optimization can be seen as two nested loops. The outer loop is controlled by the optimization software and inside that loop works the calculation engine. The optimization software interacts with the calculation engine via function values and parameter values. Using the parameter values the engine calculates and reports the required function values back to calling optimization software (see Figure 1). In many practical cases the required number of calculation loops can easily be several thousands and thus the requirement on the engine efficiency is extremely high. The calculation engine might also pre-process the model based on the given parameters. In practice, the results must be always post-processed in the calculation engine in order to obtain the required results for the optimization software. This result post-processing may also be computationally demanding task. In big simulation studies as many analysis cases as the hardware infrastructure allows should be analysed in parallel.

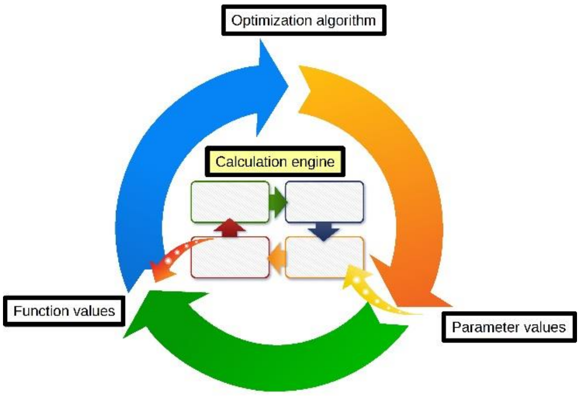

Figure 1. An automatic calculation engine incorporated within optimization.

A calculation engine can be based on several programming languages. In the very simplest case it can be only a shell script that submits analysis code to the computer into execution and fetches the required results after the run has been completed. For complex cases where the model pre-processing as well as results post-processing is required, a more general programming language may be more effective. Chaining the various analysis types or software might also be necessary, which in turn might require special processing between the runs. It is moreover beneficial if the same script can be without any major modifications run under different computer operating systems. Python scripting language fulfils these requirements well and the whole automation can be programmed with it. The developed calculation engine is based on the idea that both the calculation model and the analysis process can be based on parametrized template files. These template files are simple text files which can be easily edited with any text processing program. The calculation engine reads the parameter values, writes the model input files and then submits the analysis run files to execution. In this way not only numerical data can be parametrized but also more complex model or analysis features. As an example whole element groups describing certain sub-structures in the design can be treated as parameters. The template model can also have string type parameters describing mutually interchangeable sub-models. With the help of these kind of parameters, the optimization of structural layouts becomes possible.

VIBRATION ANALYSIS EXAMPLE

In the example analysis structural vibrations were studied. VTT's test diesel engine-generator set is a good platform for the development and testing of automatic calculation and optimization procedures. First the calculation engine conducts the free vibration analysis. The forced vibration responses are then obtained with the modal superposition method. The results post-processing includes both the analysis of the mode shapes and the analysis of the forced response results. In each optimization step some of the key results are also stored separately. Also the parameter values as well as the function values of the optimization are saved in each step. The modularity of the calculation engine enables the replacement of the analysis software or the use of different software in parallel. The pre- and post-processing are inherent part of the optimization and must be easily configured. In vibration studies one might want to follow how the frequencies of different natural mode shapes vary with different parameters. To identify the natural mode shapes, a correlation function called modal assurance criteria (MAC) can be used. If the calculation model has several millions of degrees of freedom and many mode shapes are to be analysed, the required matrix calculation can become computationally expensive. One way to overcome this is to use some limited number of degrees of freedom in comparisons. Programmatically very effective program can be created using the NumPy module (Python library) which has very effective functions for vector and matrix operations. The engine operation was simulated using engine excitation forces obtained by simulating engine internal processes. Velocity responses at engine-generator set locations were considered in the optimization. Post-processing of the vibratory results was also included in the calculation engine. It sums all the engine harmonic components into one function and finds the maximum values within a given rpm-range. It returns also the total mass which can be used as the objective function in the optimization studies.

CONCLUSIONS

An automatic calculation system can decrease dramatically the total time needed to obtain result for design problems. Also the quality of the results is improved as the calculations are made systematically and traceability is ensured. The next natural step is to incorporate the automatic calculation system as a calculation engine within optimization software. If the calculation system is sufficiently general and based on templates for the model and analysis, then the integration with optimization is possible with minimum effort. Modern scripting languages combined with the wide range of commercial and non-commercial software offer great possibilities to develop versatile and effective calculation systems that help users to meet ever tightening productivity and quality demands in product design and development.

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24. REFINING CONTEXT SPECIFIC PROJECT SUCCESS FACTORS USING ELO METHOD

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ABSTRACT

Successful projects are essential for the projecting industry and for companies with strong R&D activities to enable profitable and sustainable business. Unfortunately, there is only limited agreement among researchers on the factors that influence project success. Each research schools of management have a different, partly overlapping approach, and they emphasize different key factors for achieving success and the viewpoints also pose contradictions. Yet, the companies need to make decisions on which projects to invest in.

The key question in our constructive research is how to identify which success factors are relevant and valid in the corporate environment and context for a specific project? Based on project management research, experiential learning in the projects, and facilitation methods, we developed a new experiential learning oriented (ELO) method to identify relevant success factors for a company.

With this new method, a company creates a contextualized project success checklist for the project managers of the early phase projects. The implication of this research is that companies can improve the success rate of their projects and achieve better profitability. The research on project management benefits from our transdisciplinary learning school approach by gaining holistic understanding of project success.

INTRODUCTION

Successful projects are essential for the projecting industry and for companies with strong R&D activities to enable profitable and sustainable business. The research on project management boasts plenty of experience of project success factors, with several research schools of management (Bredillet 2006; Söderlund 2011). Each school has a different, partly overlapping approach, and they emphasise different key factors for achieving success. Yet it is conceivable that these different viewpoints and approaches cover typical challenges in projects and are able to describe the phenomenon of successful projects.

These approaches also uncover problems, as the viewpoints pose contradictions. There is only limited agreement among researchers on the factors that influence project success (Fortune and White 2006; Todorović et al. 2014). The variety of success factors and differing research results raises questions from the corporate point of view. Therefore, the key question in this research is how can we identify which success factors are relevant and valid in the corporate environment and the company's context for a specific project?

The purpose of this constructive research is to develop a method that takes into consideration which success factors are relevant for the company. The method is based on project management research, experiential learning in the projects, and facilitation methods. The outcome of using the method is a company-specific assessment checklist that is useful for project managers in the early phases of a project.

The method was built using a constructive research approach and it was evaluated in two companies. Company A is a large multinational industrial corporation that has research, design and manufacturing operations also in Finland. There were several development projects ongoing at the same time, and the projects were managed by the project portfolio. Company B is a Finnish manufacturing SME, with 95% of sales coming from global markets. The company has evolved from a projecting company into a product delivery company. In this paper, the focus is on Company B.

THEORETICAL BACKGROUND

Project success factors can be assessed from the viewpoint of achievements (i.e. the project itself) or from the project management viewpoint, which, in turn, focuses on the performance of the project management process (Costantino et al. 2015). Project success is usually associated with effectiveness, and project management success is related to efficiency. In reality, the perception of project success varies among project stakeholders and the relative importance of success dimensions varies across sectors, industries, roles, geography and time (Khan et al. 2013). Khan et al. (2013) argue that there are seven distinct dimensions of project success in literature: project efficiency, impact on the project team, impact on customer, business success, preparing for the future, project profile, as well as, stakeholder satisfaction. Still, most of the available literature, including the most cited instrument for assessing project success, i.e. Slevin and Pinto's 'diagnostic behavioural instrument' (Slevin and Pinto 1987), focus on the project manager (Davis, 2016).

Successful managing of a project requires learning from excellence, as well as from disasters (Gericke 2011). Unless the lessons learned, especially those related to the project management experience, are communicated to the subsequent projects, there is a risk that the same mistakes will be repeated (Busby 1999). Lessons learned include any form of knowledge, gained from the direct experience, successful or otherwise, to improve performance in the future (Jeon 2009). However, even in project-based organisations, where the projects embody most of the business functions, there are rarely any organisational mechanisms for knowledge that is acquired in one project to be transferred to and used in other projects (Prencipe and Tell 2001). Also, learning via projects only occasionally leads to organisational learning (Swan et al., 2010). Each project goes through its own cycle of intra-project learning to solve problems, rather than exploit knowledge that might already be available in the organisation (Goffin and Koners 2011).

According to experiential learning theory, learning is a process in which knowledge is continuously derived from and tested out in experience (Kolb 1984). In practice, this means that project teams learn from experience when they talk about their experience, come up with new ideas and experiment with them (Kayes et al. 2005). However, to learn from the experience, the project team must create a conversational space where the members talk about and reflect on their experience together (Abdel-Hamid and Madnick 1990). The way the learning process is facilitated is crucial to its success (Goffin et al. 2010).

OVERVIEW OF THE METHOD

The method enables the identification of relevant and valid success factors for company-specific contexts. This is achieved by having workshops and interventions in the company and preparation work by the facilitator. The method is illustrated in Figure 1.

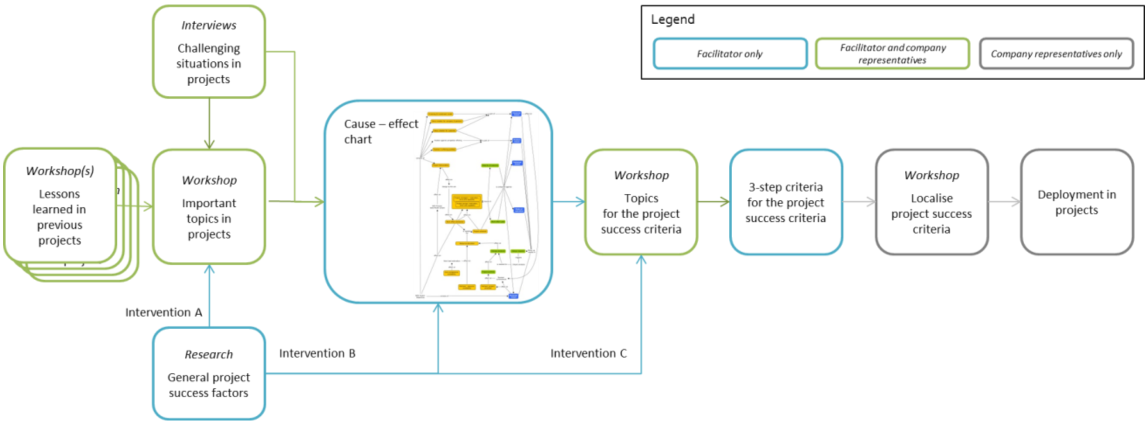

Figure 1: Overview of the method

First, the facilitator arranges workshops to capture lessons learned in previous projects as defined by Kopra (2012). He or she also interviews key personnel to identify the challenging situations in the projects. Then, the facilitator and the company representatives prioritise the findings to decide which topics are important for project success in the company. In Intervention A, the facilitator uses FocusCHAMPION cards (Juuti et al., 2015) to ensure that generally known success factors are acknowledged as well.

After the workshop, the facilitator creates a systemic cause-effect chart (Juuti and Lehtonen 2010) to reveal relationships affecting the projects in the company and to identify the root causes for problems. Intervention B means that causes are categorised as project-related and company-wide to emphasise that different types of problems are resolved by taking different approaches. In the subsequent workshop, the company representatives discuss the cause-effect chart and decide which topics will be used in the checklist. It is the facilitator’s responsibility to ensure that relevant intellectual assets, in addition to the elements in the systemic cause-effect chart, are also discussed (Intervention C).

Then, the facilitator defines the 3-step criteria for each project success factor and delivers the checklist to the company representatives. The company representatives localise the checklist and take it into use.

The method results in a project evaluation tool, including the selection of success criteria and the definition of the anchored scales for the evaluation. The success criteria are organisation- (and context-) specific and, therefore, are not applicable to other organisations or contexts.

The method is based on the following assumptions:

- The process has a sponsor, usually a senior management representative, who can offer both company resources and his own effort to the process;
- Input material, i.e. sufficient lessons learned material, is available from previous projects that are considered ideal references for assessing the future projects;
- Suitable company representatives are involved in the process, i.e. in the interviews and workshops;
- The facilitator has domain-specific knowledge related to the operational environment of the company and industry-wide best practices;

- The facilitator has sufficient access to people and information in the company;
- The organisation evaluates and updates the criteria as part of the operative project management routines

CASE EXAMPLE

Company B is a Finnish manufacturing SME that has evolved from a projecting company into a product delivery company. Currently, the engineering resources are shared between delivery projects and new product development projects. In many occasions delivery projects were prioritised over NPD projects. Therefore, the NPD projects lost resources to delivery projects and the NPD projects were delayed. Also, NPD projects were not planned in detail before the projects were initiated and here were significant delays in schedules and often the projects exceeded the initial budgets. Even after the planning phase, the project plans were often changed. Additionally, the company-wide change management practices were either ignored or described in too little detail. Also, the R&D manager had noticed that the company did not have the tools for assessing the risk level of the projects for portfolio management purposes and, therefore, the company was willing to apply the new method.

While discussing the NPD success criteria (see examples in Table 1) in the workshop, the company representatives were also comparing the NPD projects to delivery projects and selected topics for success criteria for those projects as well. The authors were not involved in fine-tuning of the topics, defining the 3-level anchored scales or the deployment of these success criteria.

Table1: Examples of NPD success criteria in Company B

CRITERIA	STATUS		
	Poor	Adequate	Good
Project funding & authority	Project is partly financed.	Project is fully financed and budget is fixed.	Project is fully financed by a reliable source and it tolerates exceeding budget by +50%. Project management can decide how the money is spent.
Value creation for business	Project ROI is more than 18 months.	Project ROI is 8-18 months.	Project ROI is less than 8 months.
Value creation for customer(s)	We do not know if the project deliverables create value for the customers. OR Project creates value less than 5% value vs. the customers' current solution.	Project creates 5-15% value vs. the customers' current solution.	Project creates value more than 15% vs. the customers' current solution.

CONCLUSIONS

The purpose of this research is to develop a method that takes into consideration which success factors are relevant for the company in a particular context. As the created construction provides answers to the research questions successfully and the method is capable of adapting to a corporate context, we conclude that the research meets the research goals.

The next step in our research is to further validate the method in small to medium-sized enterprises. The authors are also interested in studying in closer detail the effect of the method. They would like to examine how it enhances learning in projects, between projects and at the organisational level.

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25. CAN A SHEET METAL PRODUCT BE MANUFACTURED WITHOUT DRAWINGS? – PRODUCT LIFECYCLE'S POINT OF VIEW.

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ABSTRACT

This article deals with the practical problem of communicating design content between different lifecycle stakeholders. The context of research is the beginning of product lifecycle and micro-, small- and medium-sized organizations (MSMEs) (Liikanen, 2003). The suggested means to enhance the communication, and consequently improve value generation, are the removing of paper based documents, such as manufacturing drawings, and replacing them with a model based definition (MBD). Applying MBD should reduce mistakes and costs of manufacturing but is it so in real life in SME supply chain network? We study the potential and challenges of MBD with the case study of welded and painted sheet metal subassembly. The case study describes the details of the subassembly, which relates to a TFT display. The main idea is to enable 3D model as a one and only product definition source. Target is to find out is it economically and practically useful to engineer and manufacture a product in a supply chain constructed of micro size engineering office and SME suppliers, based on MBD communication. The MBD case study is compared to a real case of TFT display subassembly engineering and manufacturing. The results characterize the benefits and challenges of acting without drawings.

INTRODUCTION

The term 'product' in this context means a single part or mechanical assembly constructed by several parts. The context of this research is a Micro Size Engineering Office (MSEO) (Liikanen, 2003) in a Supply Chain Network (SCN). The industries that belong to SCN are in this context injection molding, die casting, mold making, sheet metal work, machining work, and electronics manufacturing. Industries mentioned includes several manufacturing processes such as welding, riveting, coating (plating, painting, jetting), milling, turning, grinding and stamping. This article focuses on the characteristics of sheet metal work because this industry uses lot of 2D drawings, especially in small and medium size enterprises. MSEO is typically very small company, less than 10 persons which can be as a part of very wide Supply Chain Network including different size of organizations and this leads to several challenges relating to resources and skills.

It is known, there are lot of good features to utilize 3D model files in modern 3D CAD -software and especially molding tools and 3D printed parts can be manufactured entirely or partially enabled by 3D models. However, molding tool and 3D printed part is not enough on product life cycle's point of view because they represent very narrow area of product's lifecycle. This article surveys few production methods that are usually considered when parts and assemblies have been engineered in a MSEO context. The article describes what processes relate to engineered products and whether they can be defined with or without drawings.

RESEARCH QUESTIONS AND FOCUS

The motivation to study the usability of 3D models to define product, came from the need of shorten the product development process. The need of minimizing mistakes in data transferring between engineering and production is also obvious. If 3D model could be one and only document which engineer delivers to production and other following processes, time and money saving would be remarkable. Quintana et al has studied replacing drawings with Model Based Definition (MBD) (Quintana, et al., 2010) but they studied two large aerospace companies which differs from light weight serial production companies. Quintana's conclusion was, all engineering data is not necessary to present in MBD due to challenges in long-term data storage and some practices. All companies seemed not to be ready for MBD then. In addition to that, several years later, nowadays it seems to be space for same kind of conclusion. Yet, this must be confirmed or repealed. Engrossing question is, why some companies have adopted MBD several years ago and some have been leaning to 2D drawings? It could be also asked, what prevents companies to enable MBD in all life-cycle processes. Ruemler et al. (2016) have formulated the Common Information Model (CIM) that is used as definition model for what is needed for different phases of life-cycle and domain. They realized, all information is not necessary for all and that is described in the CIM. However, according to Ruemler's research, the Common Information Model was not yet possible to establish and that need to be more investigated (Ruemler, et al., 2016).

CASE STUDY: WELDED AND PAINTED SHEET METAL SUBASSEMBLY OF TFT DISPLAY

To be able to answer the question above, it was planned the case-study that reflects to real process of product life-cycle. The product which is under study in the case, is a subassembly of TFT display used for example in railway stations. The product in the case, consist of sheet metal parts which will be welded together. The main manufacturing processes needed are stamping, press braking, self-clinching, welding, grinding and painting. When subassembly will be ready, it will be delivered to assembling process but it is not a focus in this case-study. The criteria of case characteristics are: 1) all parties need to have motivation to change the way to run processes, 2) all parties need to have ability to utilize MBD models, 3) same ability to utilize processes defined in engineering documents and 4) ability to make small series (less than 500 pcs/lot). The processes of the case are very manual because manufacturing lots are small in normal SME business in Finland. Variation of products are several and that's why production must be very flexible. It is known, flexibility is high in a small machine shops where talent personnel make decisions under various circumstances. The case process starts with engineering which gathers the customer needs and definitions. The engineering phase produces the MBD model with 3D annotations needed. After engineering, MBD model (Solidworks-file) will be sent to sheet metal shop for processing. For assembling work, it is needed to make separate guidance for operators and this can be done also utilizing 3D models. When manufacturing process will be ready, the subassembly (eq. product) will be delivered to the painting department or company. The painting guidance can be done also utilizing 3D model but the view should be just for painting. After painting, the case product is ready.

CONCLUSIONS

At this point of the research we can only tentatively confirm the possibility to utilize MBD as the means of communication in the context of the research. The planned test is on the way, but no final result has been attained. The objective of the case is to find an answer to main question, but also to sub-questions arising during the test case. Interesting questions are also if it is possible to manufacture sheet metal subassemblies without drawings, why MBD is still relatively rarely used in Finnish industry? Secondly, if it is not possible to manufacture products without drawings, what are detailed reasons for that? Furthermore, why it would be difficult to utilize MBD in SME supply chain network if it is possible in large company scale?

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