Technologies needed for Smart Pro meeting industrial challenges and problems

1. Introduction

The major goal of the pre-study is to identify and prepare the required information, knowledge, tools, modules, and technologies for a project within Smart Manufacturing in the spirit of the collaboration between Sweden and India.

WP3 focus is: Identification of the technologies needed to be considered in Smart-Pro project as an Innovation action. This means that the input technologies that will be identified in the Pre-study project should be in about TRL 3-, and the demonstrated results of Smart-Pro should be in about TRL 6-7. Smart Pro project will be based on effective collaboration between universities/research institutes and industry.

In WP3, we will develop a list of the tools, methods, modules and technologies (in the areas below) which are available at the members of the Pre-study consortium (and in industry in general), and necessary for developing Smart-Pro system.

According to the project description, WP3 has two Tasks:

- T3.1: Production-maintenance technologies needed for Smart-Pro.
- T3.2: Communication and integration technologies needed for Smart-Pro.

The tasks have been distributed between E-maintenance AB (Emaint), which the leader of the WP and the two tasks, Linnaeus University (LNU), Uppsala University (UU) and Stockholm University (SU).

Three report have been developed by E-maintenance AB and LNU jointly, UU and SU respectively. These reports have emerged in one report edited by Emaint and LNU.

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2. Technologies needed for Reliable Smart Pro to integrate production and maintenance

Based on the recently ended successfully 6-EU projects within H2020-FoF09, 2017-2021 provided us verified results concerning the technologies needed for Smart Predictive maintenance in Smart manufacturing [1]. Thus, technologies that have been identified necessary to be implemented for meeting the challenges and problems experienced by AstraZeneca and Ericsson, in addition to other companies in the same (and maybe different) branches. The detailed information concerning the challenges and problems experienced are introduced in WP2 report.

Before identifying relevant technologies necessary for developing Smart Pro system, the most important step is to identify the relevant data needed for conducting well described analysis, diagnosis, and assessment/recommendation processes. Therefore, the technologies needed can be specified in the following:

- Sensors for picking up information/data concerning different variables, such as vibration signals, sound, temperature, photos, and videos.
- Data transfer and communication links for securing data flow, communications, and the automatic functions of Smart Pro.
- Data- and knowledgebase/Cloud and REST API which are necessary for sorting data in different categories, e.g. raw data, results, photos, videos, technical and economic, saving and preparing data for future usage. In addition to having a common communication path with the cloud using REST API.
- Data security arrangement: Long term using of a digitalized and automated system such as Smart Pro with a database including data from different areas in the manufacturing processes, e.g. economic, technical, organisational, demands a well-developed data security arrangement meeting the industrial challenges.:
- IoT for digitalising manual data: In many cases, data is available in manually written register, or saved in non-completely digitalized format, for example data prepared for specific format which may not applicable for a modern digitalized and automated systems.
- Modules for optimization of maintenance and production: Smart Pro will utilize maintenance data in order to enhance production planning, secure production continuity, reduce unnecessary stoppages and prolonging production time. Therefore, it is important that maintenance is optimized with respect to improving operation and production planning.
- Modules integrating maintenance and production for planning/scheduling production based on machine condition. Such modules are primary demands for securing maintenance-production optimization, as mentioned above.

- Clear concept for Plug-and-play Smart PdM for equipment: A sophisticated Smart Predictive Maintenance is necessary to be easy to handle and use. In addition, it should have a clear and user-friendly interface. Therefore, Plug-and-Play system is one of the most interesting technologies to be addressed in Smart Pro project. The operation and recommendations of the system should be transparent and not a black box, i.e. the end user should know why, where, and how to conduct the recommendations.
- In many cases, the calculations are necessary for diagnosis, assessment/estimation and comparison, therefore applying Cyber physical system for developing Decision Support System (DSS) is necessary. This DSS should be equipped with AI and ML, enabling using even big data analytics and digital twin based on real time data acquisition -analysis-diagnosis-recommendation to answer; what, why, when and how.
- Modules for follow up maintenance and production performances from technical, economic, and organisational perspectives are also important to address, otherwise the information about changes and their times are not possible to acquire.
- End user interface (Augmented Reality and Production Line Information Visualisation, AR and PLIV): User interface can be addressed in two different perspectives;
  - One perspective is for assisting maintenance and production technicians in conducting their tasks in shorter time and as accurate as possible to reduce time losses in production. Therefore, using AR is a reliable tool for this purpose,
  - second perspective is for providing analysis/diagnosis results and recommendations to follow up production and maintenance performances which are crucial for securing production continuity and increasing production, profit and enhance company competitiveness. Therefore, PLIV is very interesting tool to be addressed for this purpose.
- Modules for follow up activities in assembling line processes. If Smart Pro system will also consider human activities, such as effectiveness and productivity of operators, maintenance and production technicians, assembly line personnel, etc., then such modules are necessary.
- Platform to integrate maintenance, production, economy, competence, etc. when there are so big number of soft- and hardware modules will be included in the design of Smart Pro. The platform should be flexible enabling adding and deleting any of the modules and allow the end user to build his own Smart Pro based on the functions demanded.
- Brain to control and stir data flow to prevent sending the end user contradicting recommendations due to having several modules may concern the same machine/equipment and problem. It is also necessary for prevention of streaming recommendations and messages.
- Smart Online tools to evaluate machines´ health/safety hazards. It is always necessary for production manager having a clear and real time evaluation of risks, such as probability of failure and assessment of the residual live.
-

- Technologies for monitoring and assessing human effectiveness and productivity. This type of technology should be selected and implemented carefully to achieve the planned objectives in data acquisition and assessment without violating human integrity.

3. Potential Loops to be considered in developing Smart Pro-system

According to the industrial experience of development and implementation of Smart manufacturing, the technologies that realized necessary to be considered in Smart Pro can be classified with respect to their functions [1]. Smart Pro system will consist of several loops reflecting its interoperability, which will be built using the technologies mentioned above. These loops are considered for providing specific functions and operation in the Smart pro system:

- **Loop (1), Data acquisition:** It aims to gather the well identified data, saved data at proper data/knowledgebase/Cloud maps to be sent for analysis at need. This loop consist of sensors for picking up the well define variable, photo/video or other information – links for data transfer – specific data-/knowledgebase – Cloud with a common REST API – security arrangements for keeping all data from hacking.
- **Loop (2), Data quality:** The major purpose of this loop is to secure the quality of the picked up data through securing that this data is collected from healthy sensors through detecting unhealthy sensor. This loop is important for prevention of faulty recommendations that are based on bad quality data. The loop can consist of one of more modules depending on the sensor types and the algorithm needed for detecting unhealthy sensors.
- **Loop (3), Predictive Maintenance Algorithm:** The role of this algorithm is to survey the condition of the machines/equipment (and also human effectiveness and productivity) based on real time data/signals/information received from the sensors mentioned above, for example sensors for vibration signals, temperature, sound, and camera for photos and videos. This loop will consist of algorithms and tools for analysis, diagnosis, and recommendations concerning, what, where, how and when to do maintenance actions.
- **Loop (4), Stress-condition evaluation:** This module aims to provide the underlying information necessary for production planner/system. It surveys all maintenance actions (using real time data) that are planned or recommended for the machine in question and assess the

- machine available time until the next planned maintenance action, which will allow a reliable production planning and secure production continuity.
- **Loop (5), Scheduling algorithm:** Production planning/scheduling can be done manually or using automatic and digitalized system for this purpose. In the either cases, a production schedule should be developed based on any a new production order. In the production schedule, timeslots for planned stoppages/maintenance should be suggested to ease optimizing maintenance with production scheduling so that all maintenance actions will be conducted in these time slots and prevent stopping production unnecessary.
- **Loop (6), Maintenance optimization**: This module is aimed to optimize maintenance planning with respect to planned production stoppages to reduce the risk of unnecessary stoppages through recommending a specific time for conducting all necessary maintenance actions without increasing the probability of failure.
- **Loop (7), Production Line Information Visualization (PLIV):** A module that should be able to downloaded using smart phone, tablet, laptop and stationery PC for automatic gathering and visualizing the information, for example, analysis results and needed raw data, from Smart Pro Cloud/database to the end user at need.
- **Loop (8), Follow up:** It is always important to follow up Smart Pro performance and its technical and economic impact on the targeted machines, production processes and company business. That is necessary to make sure that:
    1. The system conducting the functions that it was built for.
    2. The accuracy of the analysis, diagnosis, and recommendations fulfilling the company demands.
    3. The economic benefit, i.e. whether the system adds value or adds new costs: It is to quantify the system technical and economic impact, and confirm/reject that applying advanced maintenance systems adding values and not costing unnecessary more, i.e. whether it is a profit or cost generating system.

4. Additional Technologies

We have identified two technologies that are needed for establishing digitalizing/automating of production based on real world data. In particular, we have elucidated work-place safety and smart manufacturing based on machineries components such as lubricants and eventual formation of dust particle hazards:

1. Analysis of tribocorrosion and wear performance of metallic elements of machines that are lubricated. New tools need to be developed to ensure automation based on life cycle analysis. This requires sophisticated nanoscale analysis based on TEM spectroscopy. This technique will provide offline data that support the online measurements needed for digital maintenance.
2. Formation and sustainable elimination of particle-based hazards to prevent potential dust explosions in production sites. New dust collectors need to be developed that ensure sustainable deactivation and inertization of reactive particles.
3.

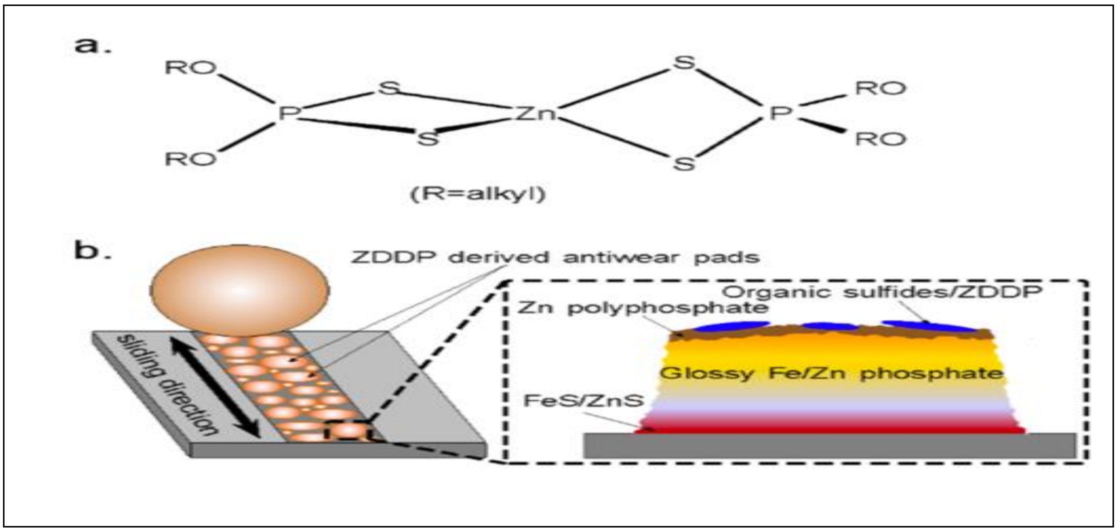

Figure 1. (a) Schematic representation of the zinc dialkylthiophos- phate (ZDDP) molecule.

(b) Schematic representation of the protective tribofilm formation from the ZDDP additive in a lubrication oil during a ball-on-disk tribotest. Scheme inspired by Spikes [2]

Concept 1: Lubrication of an internal combustion engine is crucial for reducing unwanted energy and material losses and thus expanding its fuel efficiency and life-time. In order to achieve this, two types of additives, which are mixed into the lubricating engine oil, are critical: friction modifiers and antiwear additive, Figure 1, [1,5]. The constant improvement of high-performance analytical techniques such as (scanning) transmission electron micros- copy (STEM) combined with electron energy loss spectroscopy (EELS) and EDX as well as an innovative approach for data processing methods described in our previous work permitted us recently in the present work to detect and characterize the end products of ZDDP obtained from engine oils [6,7]. These are critical information and also the basis of toxicity assessment, both for theoretical predictions and experimental testing for the estimation of overall life-cycle analysis, including the environmental impact, Figures 2 and 3.

For stage 2, we intend to improve production safety based on the current state of the art by applying predictive tools for wear- and tribocorrosion performance of metallic machinery parts [8-10]. We will use our recently developed TEM data fusion method in combination with electrochemical tribocorrosion analysis. This will ensure that we understand the life cycle of the machinery parts and identify potential particle hazards originating from machines operations.

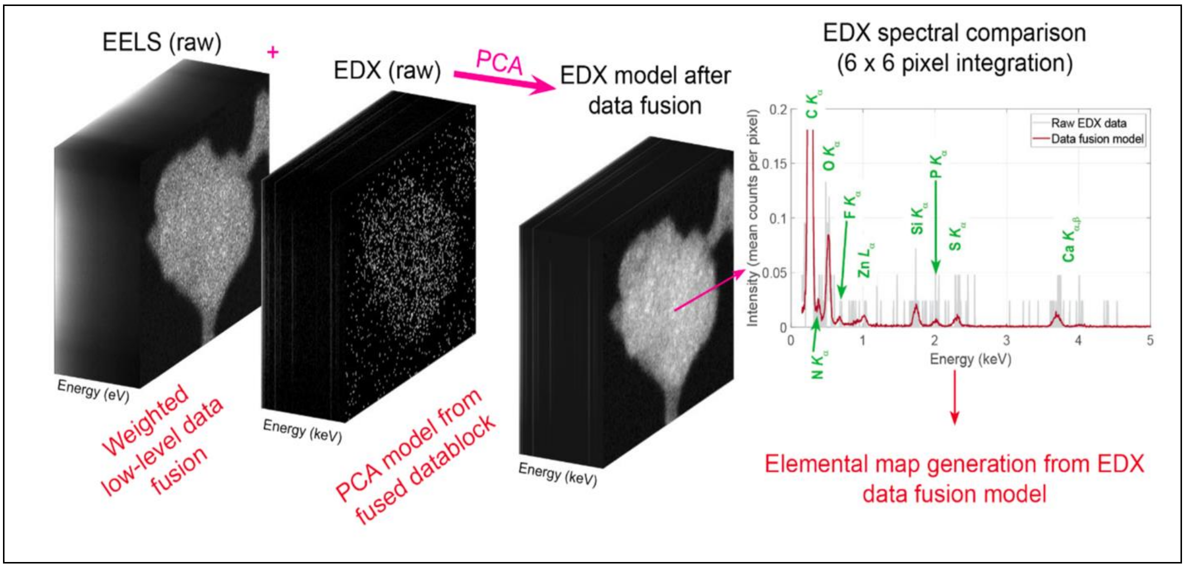

Figure 2. Schematic of the low-level data fusion approach employed for estimating compositional maps with EDX.

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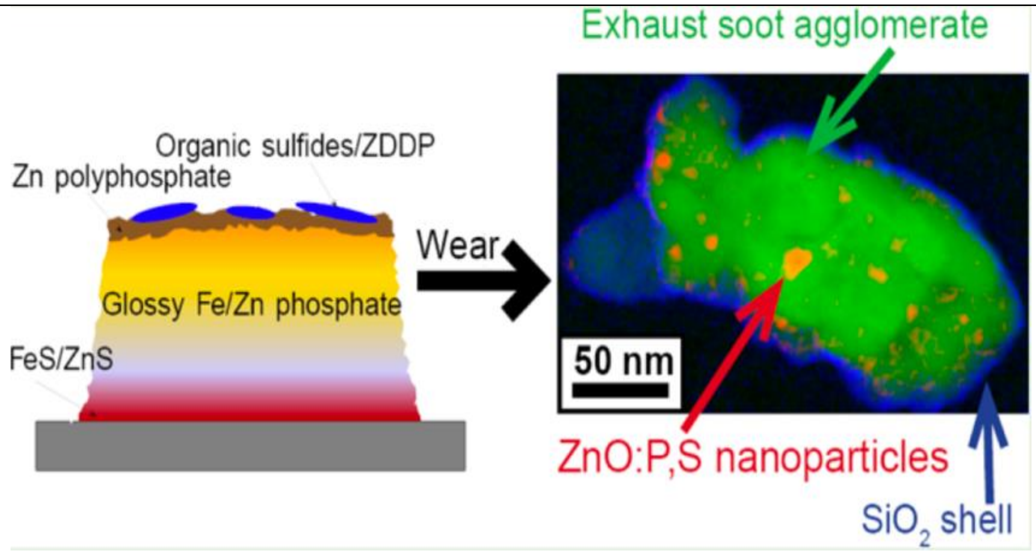

Figure 3. Decomposition mechanism of ZDDP-additives in base oil lubricants visualized with the data fusion method.

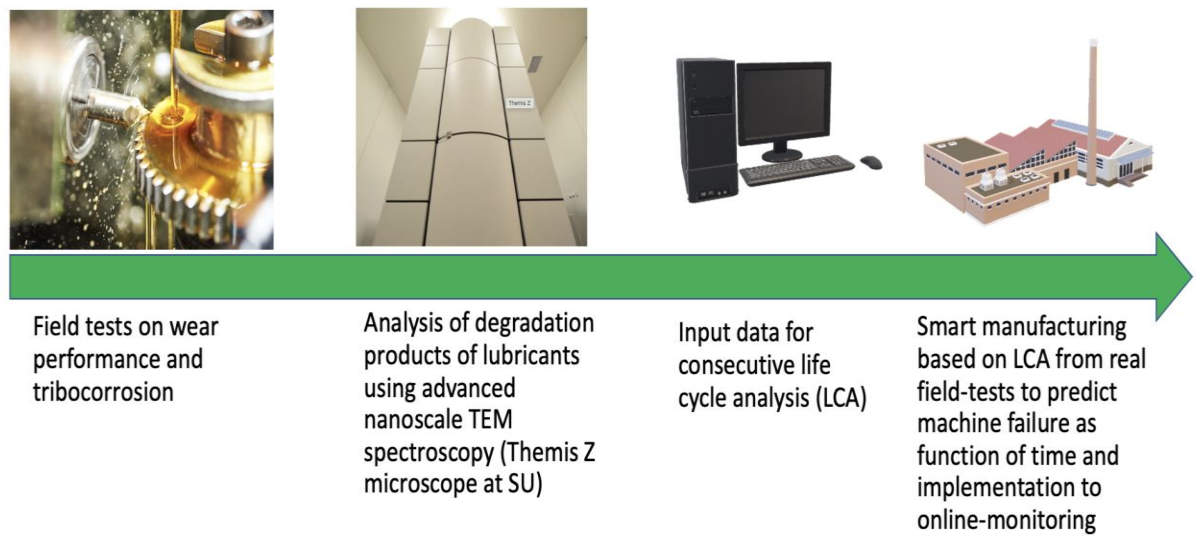

Figure 4. Required technologies to assist the smart manufacturing with respect to zero waste and production safety.

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Concept 2: The elimination and deactivation of undesired chemical side-products in industrial production is becoming increasingly important and the recycling and recovery of hazardous and valuable components has to be addressed and implemented as part of manufacturing cycle. Industrial manufacturing often generates fine powders in the form of dust and waste. This applies not only to the metal industry, but also to the automotive, electronic, ceramic, and plastic industry, also including the rapidly developing additive manufacturing technology. The International Organization for Standardization (ISO 4225-ISO, 1994) defines dust as small solid particles, conventionally taken as those particles below 75µm in diameter.

These particular impurities represent a serious environmental, health and safety hazard such as spontaneous ignition and risks associated with the impact of fine particles on the working environment; it is thus important to minimize the release and exposure to fine particles during the whole production process. Our analysis has revealed that currently particle hazards (based on Al-particles for example) are only collected in aqueous containers, which represents a hazard due to lack of deactivation of these reactive particles. We intend to develop in the future dust collectors that have an integrated inertization technology to exclude particle hazards, Figure 5. We have discussed with a dust collector company that could help us to construct such new systems. This will focus on the use of biobased (cellulose, lignin etc) membranes, filters and catalysts that combine capture of dust particles and degradation as well as reuse of the membranes. [11,12]

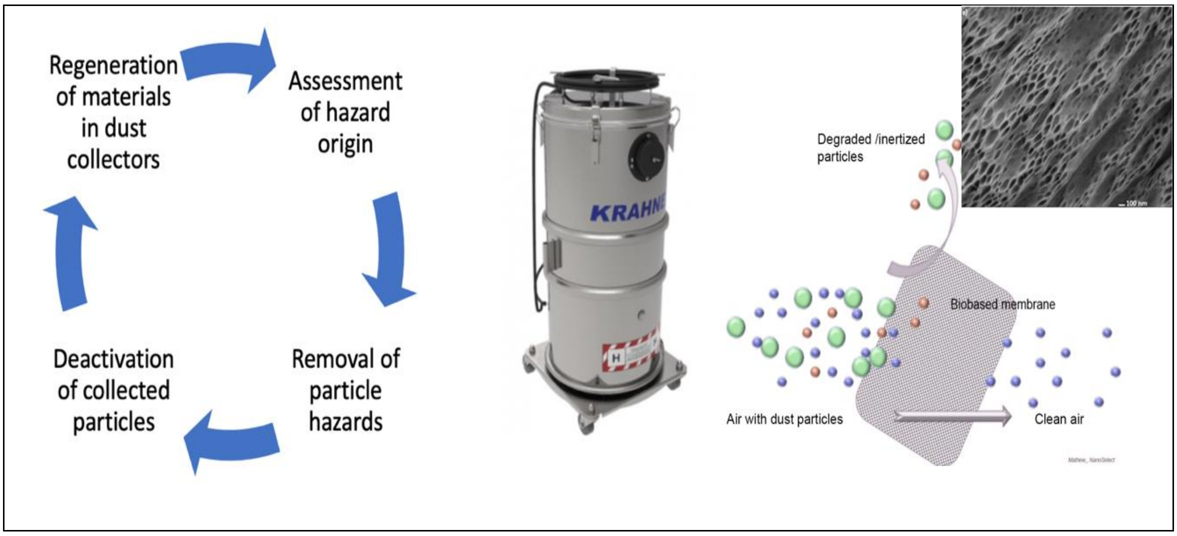

Figure 5. Plan for stage 2 application: proposed technology of dust collectors for ensuring indoor production safety aiming at zero waste; Nanoporous biobased membranes useful for removing and degrading dust, bacteria and other pollutants in air

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5. Driving Aspects of Future Smart manufacturing

Acronyms

MMG - Microwaves in Medical Engineering Group RFID - Radio Frequency Identification

WSN - Wireless Networks GUI- Graphic user interface DL- Deep Learning

IOT - Internet of Things

IOT – Industrial Internet of Things

In this chapter, we cover the basic definition of smart production and the driving aspects for future manufacturing sectors.

5.1 Smart Production

Smart Production is needed to accelerate a connected workforce for continuous improvements to drive greater productivity and efficiency inclined towards reducing the total ownership costs and increase profitability. The driving aspect of future manufacturing can be classified as:

1. Modularity: Higher effectiveness in productivity.
2. Autonomy: Response to unexpected events in an intelligent and efficient way.
3. Connectivity: Highly precise product design.
4. Digital Twin: PLM with high accuracy.

Different technologies are involved in Smart Manufacturing Process, such as:

1. Digital Twin: Increased reliability, reduced risk, lower maintenance costs, improved production-on, Faster time to value, predictive maintenance.

   For manufacturing and healthcare:

   a) Digital footprint of all the products throughout their entire Product life-cycle management.

   b) Predicting future manufacturing process based on available day to day data.

   c) Data driven approach to maintain the health of the samples. [13]

2. HMI/SCADA: Precise monitor control, visualize the operations using intelligent control systems.

3. IIOT
    a) Deliver insights to the right people at the right time.
    b) Adapt to meet your customer demands.
    c) Drive short term and long-term decisions around equipment, people, suppliers, Figure 6a, [13].

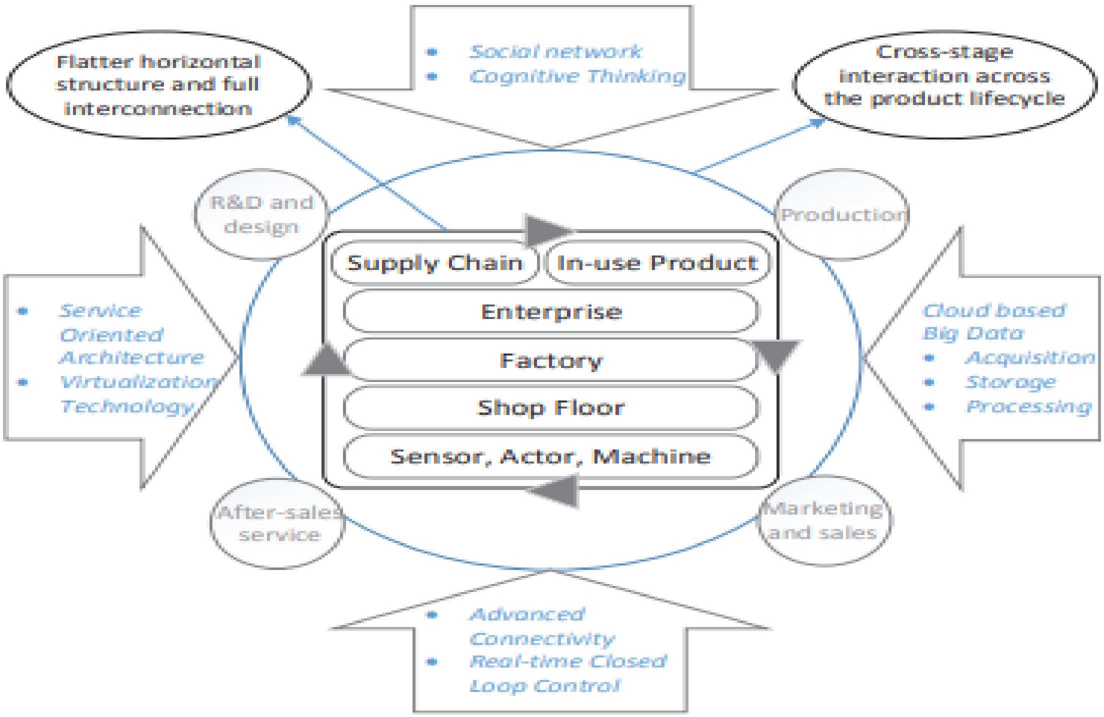

Figure 6a: Cloud – centric framework for an industry depicting the chain of technologies involved in digitalizing an industry.

4. Unsupervised Machine Learning: Algorithm driven, deep learning of sensor data in real time with no data required by the factory personnel for deployment on-site with auto updates on machine model concluding to zero on-boarding costs. [13]

5. Manufacturing Execution System:

    a) Proactive Control & Quality

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b) Granular Enterprise Visibility

c) True Continuous Improvement

d) Brand Risk Reduction

e) Improved Profit Margin [14].

Application of IoT in current manufacturing processes in industries is briefly described on application and its deployment with respect to:

1. Virtual organizations
2. Surveillance systems
3. Remote manufacturing
4. Internet based manufacturing
5. Coordinated measuring systems.
6. Computer- Integrated manufacturing systems

In order to achieve smart manufacturing, all these technologies need to be integrated in a unified network system in contrast to information and knowledge driven existing technology to improve the efficiency of production lines and life-cycle costs.

5.2 The supporting technologies that can be necessary for IOT

1. Radio-frequency Identification:

   RFID: This technology uses EMF (electromagnetic field) as the medium for transferring data, it is used for unique identification of machines with the tags attached to each machine. The RFID tags holds information about each machine with no need of maintaining a separate report by the enterprise system. In production lines RFID can be applied for production scheduling and resource management, Figure 6b.

2. Wireless Sensor Networks

   Wireless sensor networks [WSN]: WSN are composed of autonomous nodes which are spatially distributed to sense the surrounding environment, other node communication and to perform computations. The connectivity is not at all affected by the distance since the nodes are self-organized in such a manner to maintain the best connectivity to the base station. In production lines WSN have wide prospect in scenarios where sensing-based manufacturing is used for decision making, Figure 6b.

Figure 6b. Real world ZigBee Architecture for tracking, locating and monitoring the products manufactured inside the company for predicting the lifetime and quality before and after its delivery to the customer. [16]

3. Cloud Computing & Big data

Cloud Computing and Big data: Cloud computing technology efficiently manages a large amount of shared pool data concerning to computing resources that can be easily interrogated and sent out with minimal effort based on virtualization technology and Service oriented Architecture. With such humongous data collected by cloud computing techniques demands a need for big data management generated by manufacturing IoT. Due in inadequate advancement in normal data management Big data term came into existence which comprises of 3 V's such as:

1. Volume: Can easily account for data more than terabytes.
2. Variety: Different types of data such as well structured, unstructured, text, video, images.
3. Velocity: required/set time for data processing and frame creation.

The work cycle of big data management consists of: Data Acquisition, Data Extraction, Data Integration, Data Analysis & Interpretation. In production sector, Big Data will help in maintaining the full life-cycle details of the manufactured products which brings up a significant change in design, quality customer satisfaction and how efficiently a product is manufactured, Figure 6a.

Issues to be Addressed at Deployment:

1. Problems with WSN
2. Initial cost and benefit calculation of WSN
3. Where and how much sensors should be deployed
4. Steps involved in WSN deployment
5. How do we receive update and maintenance plan for WSN?

5.3 Highly Beneficial factors in using Iot.

1. It can monitor and maintain automation and efficiency of the machines in different work floor
2. Energy management in the production lines
3. Proactive Maintenance
4. Connected supply chain management. [15]

WSN has been recognized one of the most important technologies in the century in comparison to wired computer networks, WSN is expected to be a low-cost solution. WSN is open to accommodate new devices any time, and it is flexible to go through physical partitions. Moreover, WSN is ideal for non-reachable places for temporary network setups. Numerous prototyping WSNs have been developed for the applications in geophysical monitoring, precision agriculture, habitat monitoring, transportation, military systems, and business processes. [16]

The studies of WNS are very challenging since it requires an enormous breadth of knowledge from different disciplines. In designing a WSN, traditional technique for analyzing the performance of a WSN can be classified into analytical methods, computer simulation, and physical measurement. It is necessary to develop both of qualitative and quantitative approaches for data mining and reasoning in designing and operation of a complex system. However, sensor networks often have the physical constraints such as energy limitation, decentralized collaboration, and fault tolerance necessitate, which defy analytical methods with complex algorithms. Furthermore, few sensor networks have come into existence due to various unresolved issues; the measurements are virtually impossible. As a result, simulation is currently the primary practical approach to analyze WSN quantitatively.

5.4 Importance of simulation in WSN:

1. Test-beds are expensive for physical testing of WSN, hence it is more cost effective and economical unless there is need for real testing at the final development stage.
2. Debugging the WSN in network or node level is quite challenging and complicated due to large number of sensor nodes.
3. Applications of WSN in chemical laboratories or in no man environment could be challenging and very expensive.
4. Hence a simulation enables us to keep the operations under control with the help of Graphic User Interface (GUI), this allows the operators/users to directly interact with WSN to visualize its ongoing status, Figure 7.

Henceforth, Graphic visualization is one of the critical features of simulation which minimizes the effort and time required for physically debugging the sensor nodes. So, the obtained data from devices are represented graphically which is one of the most effective way to examine a problem. There are 3 ways in which WSN can be visualized they are 3D models, AutoCAD drawings and Canvases, Figure 8.

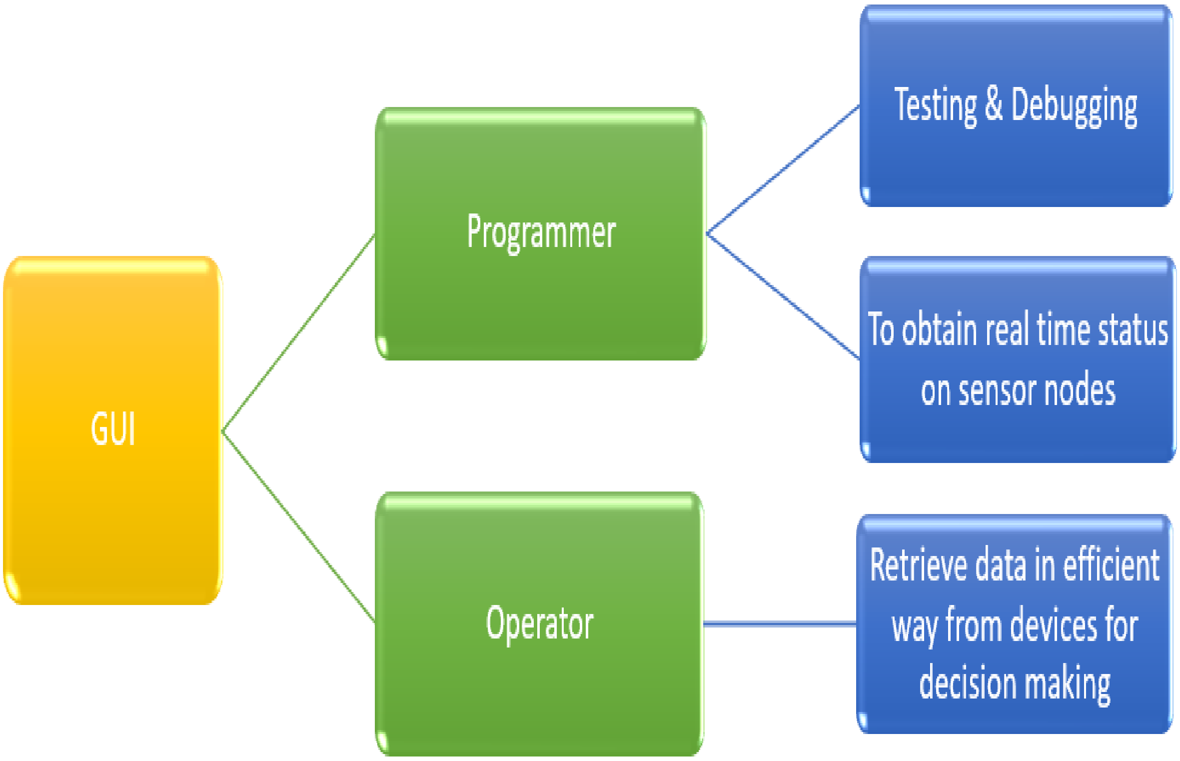

Figure 7. Workflow of GUI explaining the functions of programmer and operator during the image visualization.

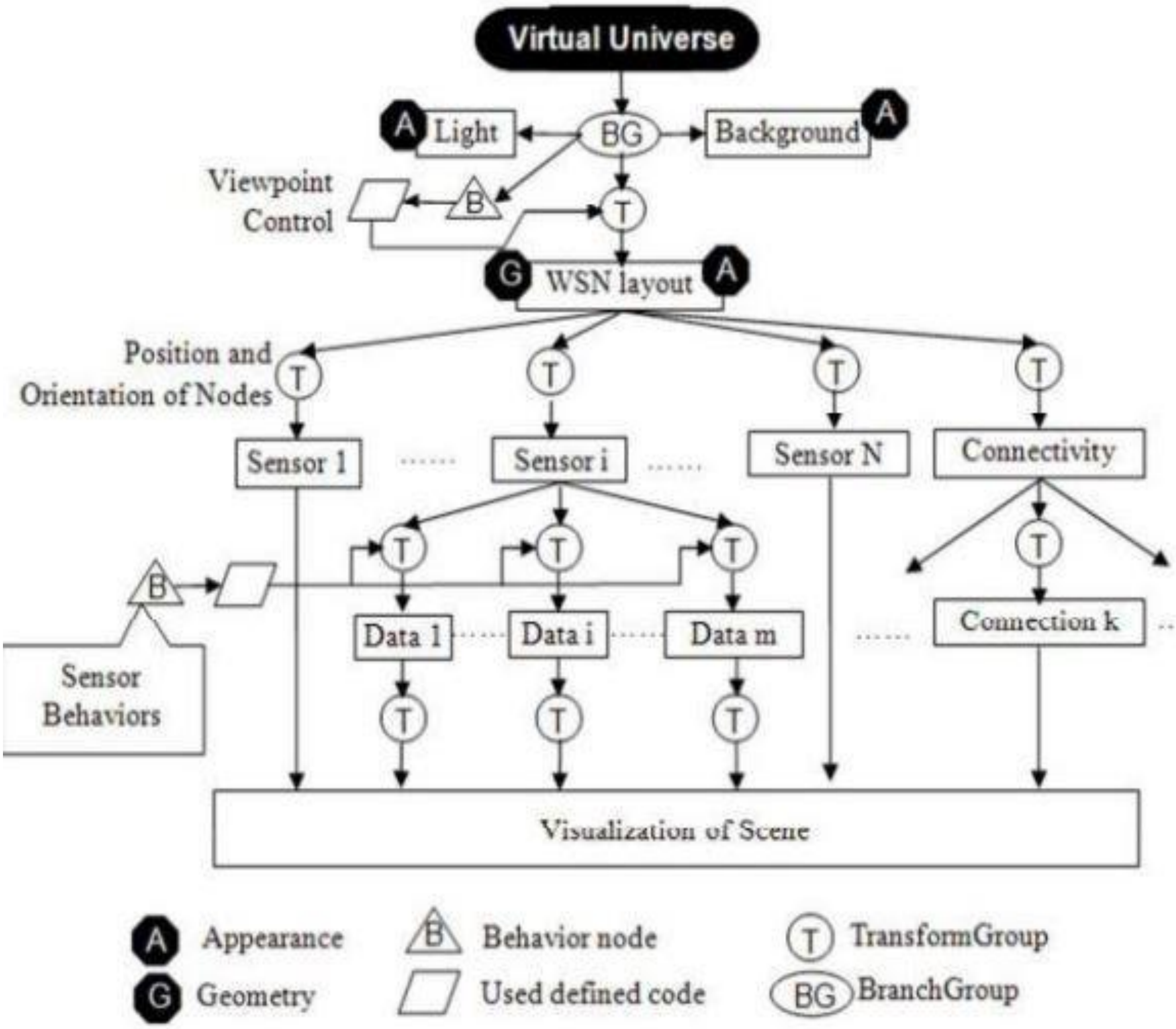

Figure 8. Flowchart of WSN model explaining various modes in accordance to working / results given by the sensors[16]

5.5 Data driven method for predictive maintenance

The deployed data driven approach utilizes cutting edge technologies provide information regarding the real time status of each machine. Since the data collected are large and more easily available Deep Learning (DL) would be more effective in predictive maintenance.

As seen in the figures 9 and 10 below DL consists of stages i.e.

1. Learning phase (model trained based on historic data from sensors and respective devices)
2. Trained Phase (Model acts accordingly to predict errors and take actions).
3. On the whole every phase consists of sub phases such as:
   a) Pre-processing of data and acquisition (single sensor or multi sensor nodes)
   b) Feature Engineering
   c)Training given to models. [17]

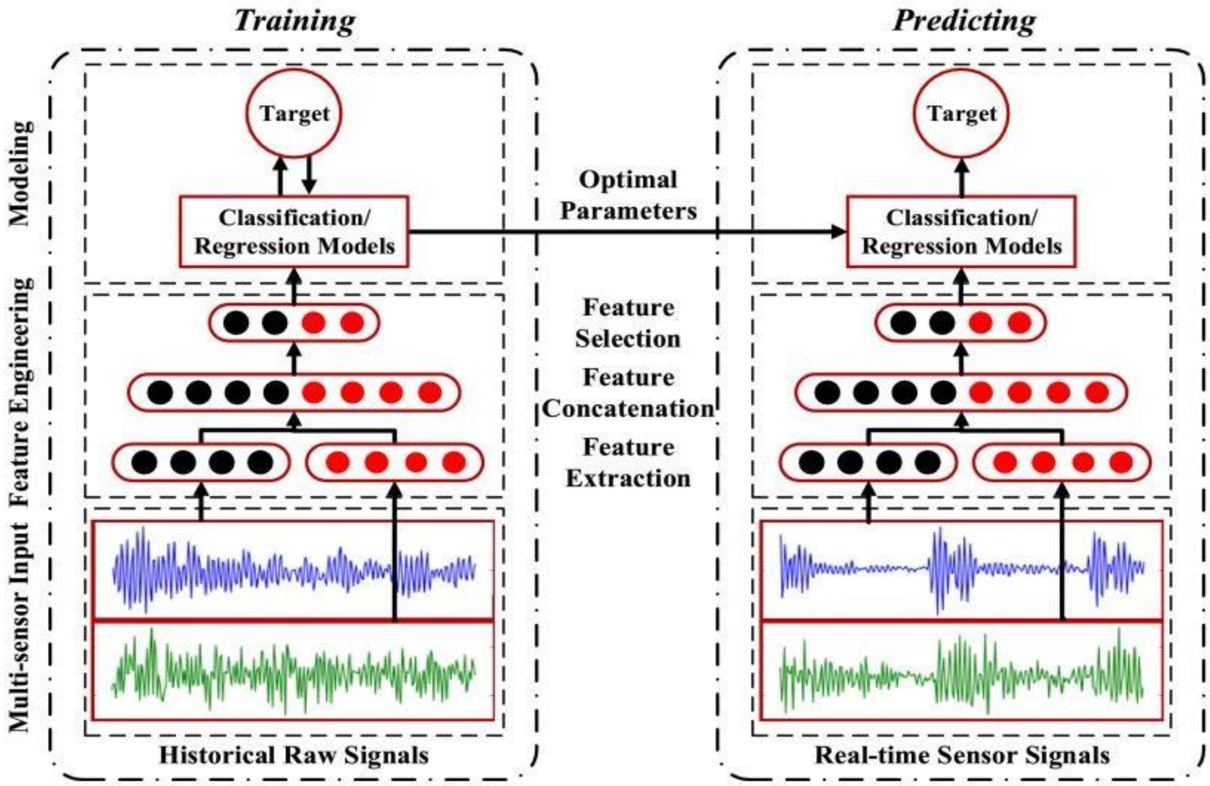

Figure 9. Flowchart depicting data driven approach for PM with a detailed description of how process involved during training and prediction level of a model [17]

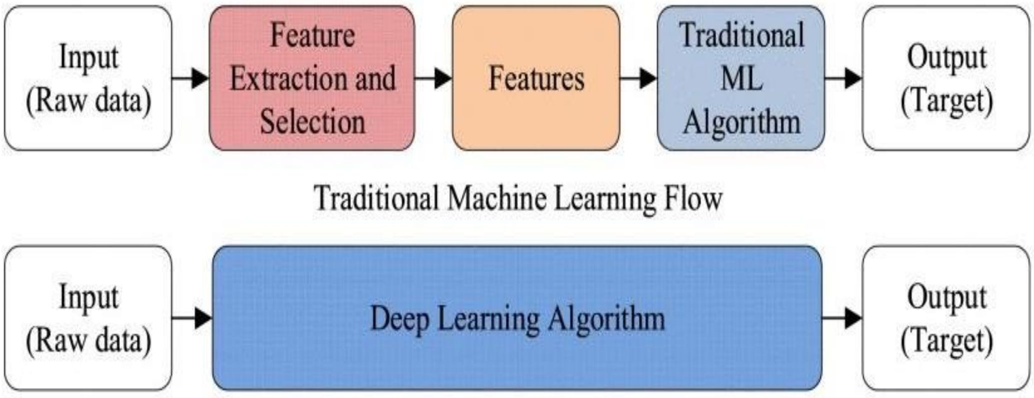

Figure 10. Comparison of iterations involved in normal machine learning and deep learning algorithm. [17]

Summary

The forementioned technologies helps in digitalizing an normal work floor in the existing factories which when achieved need no human to carry out basic operations during the manufacturing process which incorporates intermediate checks on machines efficiency, product quality, elimination of unwanted events thus improving the workflow of the production line without interruption. On top of these we do have more technologies which can be executed to digitalize the existing manufacturing work floor and maintenance technologies.

One of the interesting technologies would be **Haptic interface** – a human computer interaction technology based on bodily movements and sensations to perform actions or processes in the computer device. Utilization of Haptic interface in Manufacturing consists of:

1. Human Haptics: Perceived by humans relatively through touch.
2. Computational Haptics: A individual software developed to touch and feel virtual objects.
3. Machine Haptics: A special kind of machine designed for usage of machinery which can replace human touch.

Haptic machine interfaces can allow machine to operate remotely, giving a live experience for the user in the way he does on site. On the other hand, combining virtual reality and artificial intelligence in 3D scenarios with haptic feedback can be used in many manufacturing industries such as simulation training for new trainees and, also studying brain-computer interfaces with receive haptic feedback within their stimuli. [18]

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References

(1) Foresee Cluster (foresee-cluster.eu)

(2) [2]) Spikes, H. The History and Mechanisms of ZDDP. Tribology Lett. 2004, 17, 469−489.

[3] Tang, Z.; Li, S. A Review of Recent Developments of Friction Modifiers for Liquid Lubricants (2007-Present). Cur. Opn. in Solid State and Mater. Sci. 2014, 18, 119−139.

[4] Khorramian, B. A.; Iyer, G. R.; Kodali, S.; Natarajan, P.; Tupil, R. Review of Antiwear Additives for Crankcase Oils. Wear 1993, 169, 87−95.

[5] Li, W.; Kumara, C.; Luo, H.; Meyer, H. M.; He, X.; Ngo, D.; Kim, S. H.; Qu, J. Ultralow Boundary Lubrication Friction by Three- Way Synergistic Interactions among Ionic Liquid, Friction Modifier, and Dispersant. ACS Appl. Mater. and Inter. 2020, 12, 17077−17090.

[6] Thersleff, T.; Budnyk, S.; Drangai, L.; Slabon, A. Dissecting Complex Nanoparticle Heterostructures via Multimodal Data Fusion with Aberration-Corrected STEM Spectroscopy. Ultramicroscopy 2020, 219, 113116.

[7] Thersleff, Jenei, Budnyk, Dörr, Slabon, Soot Nanoparticles Generated from Tribofilm Decomposition under Real Engine Conditions for Identifying Lubricant Hazards. ACS Appl. Nano Mater. 2021, 4, 220−228

[8] Barnes, A. M.; Bartle, K. D.; Thibon, V. R. A. A Review of Zinc Dialkyldithiophosphates (ZDDPS): Characterisation and Role in the Lubricating Oil. Tribology Inter. 2001, 34, 389−395.

[9] Zhang, J.; Ewen, J. P.; Ueda, M.; Wong, J. S. S.; Spikes, H. A. Mechanochemistry of Zinc Dialkyldithiophosphate on Steel Surfaces under Elastohydrodynamic Lubrication Conditions. ACS Appl. Mater. and Inter. 2020, 12, 6662−6676.

[10] ACEA European Oil Sequences 2016 Rev. 2, December 2018 https://www.acea.be/uploads/news_documents/ACEA_European_oil_sequences_2016_update_REV_2.pdf (accessed Nov 5, 2020).

[11] Aguilar-Sanchez A., Jalvo, B., Mautner A, Nameer S, Pöhler T, Tammelin T, Mathew AP, Waterborne nanocellulose coatings for improving the antifouling and antibacterial properties of polyethersulfone membranes, J Memb Sci., 620, 118842, 2021.

[12] Mathew AP., Lui P., Karim Z. Lai J. Nanocellulose based membranes for water purification: Fundamental concepts and Scale-up potential, In: Nanocellulose and Sustainability: Production, Properties, Applications, and Case Studies / [ed] Koon-Yang Lee, CRC Press, 2018, p. 129-146

[13]I-Scoop, *Smart-Manufacturing*, [Online]. Available: https://www.i-scoop.eu/industry-4- 0/manufacturing-industry/, (Accessed: 2021, May 25).

[14] Siemens, *Manufacturing Execution Systems*, [Online]. Available: https://www.plm.automation. siemens.com/global/en/products/manufacturing-operations/manufacturing-execution-system.html?gclid=CjwKCAjwgOGCBhAlEiwA7FUXklaQdXcXDn-X1rrdYc4DE8Y2Yz_gm5tFp6CuxOjmblo BwE, (Accessed: 2021, May 25).

[15] C. Yang, W. Shen og X. Wang, „Applications of Internet of Things in manufacturing “, í *2016 IEEE 20th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*, 2016, bls. 670–675. DOI: 10.1109/CSCWD.2016.7566069.

[16] P. Wang, S. Chaudhry, L. Li, Z. Bi, G. Wang og L. da Xu, „A visualization platform for internet of things in manufacturing applications “, *Internet Research*, 2016.

[17] A. Caputo, G. Marzi, M. M. Pellegrini, M. Al-Mashari og M. Del Giudice, „The internet of things in manufacturing innovation processes: development and application of a conceptual framework “, *Business Process Management Journal*, 2016.

[18] Contreras Masse, R., 2019. Application of IoT with haptics interface in the manufacturing industry. *Instituto de Ingeniería y Tecnología*.