Smart Maintenance Model using Cyber Physical System

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Abstract - Modern manufacturing are exposed to rapid and dynamic changes in operating conditions, market demands, national and international competition. Therefore, new generations and concepts of maintenance techniques are necessary to overcome the deficiencies in the current techniques. The purpose of this paper is to propse a maintenance model that is automatic, digitzalised and intelligent using Cyber Physical System (CPS-Maint). In this paper, we presented comparable maintenance approaches and described their shortages. Thereafter, we developed a new maintenance model. Then, A simulation using LabVIEW is conducted to examin the model and its behavior. The results showed that the required tasks are performed with no conflict among its components. The major result is the development of CPS-Maint and the major conclusion is applying CPS-Maint fulfills industry needs. This paper provides a framework that could help developers and researchers in desining and developing an automatic and smart maintenance system.

Keywords-Cyber Physical System for maintenance, Automatic Maintenance, Condition Based Maintenance

1. INTRODUCTION

The technological advancement in industries such as the Industry 4.0 emphasis on horizontal and vertical integration, as well as, on the digital integration of engineering across the value chain, (Kagermann et al., 2013). Using such advanced technologies could bring new industrial demands and maintenance challenges. Condition Monitoring (CM) and Condition-Based Maintenance (CBM) are used since middle of the last century, (Collacott 1977) and are expected to play a significant role in the digitalized industrial. From the different CM techniques, vibration appears to be the most spread technique for monitoring rotating machines (Tandon et al. 2007; De Azevedo et al. 2016). This is because in vibration-based techniques, vibration data can be pre-processed and post-processed on time domain, frequency domain and time-frequency domain. Therefore, this technique is a versatile and complete tool to identify useful information caused by most possible faults, deterioration process and damages either localized or distributed, see (De Azevedo et al. 2016).
In general, the process of vibration analysis is done manually, which is extensive in labour, knowledge and experience. For this reason, it is not possible to monitor machines continuously. Using commercial vibration measuring systems, there is no possibility of predicting the condition of a machine in the near future in an objective way. Personnel estimate the future development of damages occasionally and subjectively. which means very high risk of discontinuity in production due unexpected damage development and therewith failures. Furthermore, the more often measurements of relevant information the less the probability of missing changes in the state of a machine and therewith low probability of failures, and vice versa (Sherwin and Al-Najjar 1999). In the case of machines which stoppages are intolerable (i.e. expensive or safety threating), relevant and reliable information at reasonable frequency is necessary even if it costs more.

Industry uses lubrication to reduce friction and therewith wear rate in order to prolong machine life. In some cases, a central lubrication system is applicable. Bearings that are not lubricated centrally are greased manually and regularly unrelated to the condition of the component and the real need. In addition, some of these bearings can be in inaccessible areas, i.e. areas of high temperature, radiation or risk of accident, preventing reliable monitoring of machine condition or greasing it without stopping the production, which increases the likelihood of failures or production losses respectively. Therefore, it is necessary to develop new generation of maintenance systems to overcome these serious deficiencies and sustain realization of Industry 4.0 in a cost-effective way. Therefore, the problem addressed in this paper is: How to improve maintenance decision accuracy and capability, and to provide self-healing ability, i.e. automatic and quick actions, at need especially in inaccessible areas?

A Litrature review showed two concepts and one commersilized solution found to be relevant to the addressed problem in this paper. The concepts are: Self-Maintenance: (Lee et al., 2011), (Labib, 2006), (Singh et al., 2014), (Echavarria et al., 2007), (Karray et al., 2011), (Umeda et al., 1994), and Engineering Immune System: (Lee et al., 2011). Self-maintenance (SM) is a design and system methodology. It is the machine ability to diagnose, prognoses and recovers its main/some functions when failure happened or about to happen. This is performed by trading off the functionalities and by reconfiguring its parameters, where the main fuction remains but it is performance might degrade (Labib (2006), (Singh et al., 2014), (Lee et al., 2011), (Umeda et al., 1994). Engineering Immune System (EIS) system is a design concept that has been adapted from the biological immune system, which identifies and protects against infections. The aim of EIS is to avoid disturbances instead of compensating by control or recovering the system by physical maintenance, (Lee et al., 2011). EIS has robustness in diverse and dynamic environment, adaptability to learn and respond to new damages, adaptability to retain memory to assist future responses, and autonomy for self-controlled ability with no requirement of external control. The relevant commerisilized solution is Smart eMDSS (eMaintenance Decision Support system). According to Holmberg et al. (2010) and Al-Najjar (2012), it is a system for monitoring the condition of equipment/component, detect damages, evaluate damage severity, predict damage development in the near future, follow up maintenance and production performances and assess maintenance economic contribution to company business.
The review of SM and EIS showed that the two concepts are design concepts and implementable at the design stage. Therefore the aim of this study is to develop an intelligent maintenance model that is implementable at the operation stage using relevant CM monitoring techniques (e.g. vibration and temperature) and Cyber Physical System technology. This system will provide the machine with self maintenance abilities.

The rest of this paper is organized as follows. In Section 2 the maintenance model is developed. Section 3 simulates the model and present the results. Finally, in Section 4 conclusions are derived.

2. MODEL DEVELOPMENT

Cyber-Physical System (CPS) is a new paradigm that seeks to combine and coordinate physical and computational elements. It consists of computing facilities, communication, data gathering and storage to monitor and control entities of the physical world in real time, (Lui et al., 2008) and (Penna et al., 2014). Robots, intelligent buildings, self-driving cars or airplanes are examples of CPS, (Sztipanovits et al., 2013), (Lui et al., 2008). In this paper, we developed a model for an innovative: Cyber Physical Systems for intelligent CBM (CPS-Maint), for supporting the applications of the digitalized and automated industries such as when applying the concept of Industry 4.0. The model development is based on upgrading, digitalizing, integrating and automating CBM process. To reach an auto-maintenance system that fulfils the industry needs, this system should be able to automatically: 1. Gather the measurements/data required, e.g. vibration, for monitoring the health of a machine. 2. Recommend actions or send work orders. 3. Conduct specific maintenance actions, and 4. Report about what maintenance actions, when and where to be done manually.

This type of systems can be equivalent to integrating an intelligent maintenance system with experts in maintenance and production, because digitalizing maintenance process eases reliable and effective communication within the company. Consequently, it eases for the decision makers to access the required underlying information needed to achieve fast and accurate decisions. CPS -

Maint takes a big step towards globalization. It eases communicating and exchange of data, experience and knowledge, for example concerning machine condition, damage initiation, progression, and ways of avoiding or reducing damage development, between manufacturing companies.

Brynjolfsson and Andrew (2015) introduced the test results of a software program developed for competition in chess games in the following way:

- Computer with software program for specific purpose + amateur user + better process provides much better results than,
- Computer with the same software program + professional/expert user + bad process.

In this paper, we consider eMDSS, which is commercialized by e-maintenance Sweden AB as Smart eMDSS (Smart eMaintenance Decision Support system). It is considered due to its successful applicability in industry, and its possibility to be expanded to CPS-Maint. Linnaeus University in Sweden and E-maintenance Sweden AB developed further Smart eMDSS to fulfil the following theme:

- Computer with analysis, diagnosis and prediction software + well-developed and friendly user-system interface + inexpert user + well-developed and easily understood diagnosis and prediction process.

Which should be better than,

- Computer with the same software + expert user + not well-developed and user friendly interface + not well-developed and difficult understood diagnosis and prediction process.

To develop a model describing the construction, interfaces and functions of CPS – Maint, we first identified the elements consisting CPS-Maint process, which is divided into six major tasks:

1. Machine identification; identify the machines and components that will be monitored.
2. Data gathering Measuring system; it is to pick up data, e.g. vibration measurements.
3. Data import-export and signal processing: The catch program receives measurements from wireless/wired or manually held sensors after converting an analog vibration signal to digital and processing it.
4. Diagnosis and prediction: To retrieve the vibration measurements, CPS-Maint can communicate with machine/company or measuring system database through catch program. When data have been imported by CPS-Maint automatically, it starts analysis, diagnosis and prediction of the condition of the machine, assessing the probability of machine failure and its residual life.
5. Automatic maintenance: Actuators, in this paper, are for conducting specific condition-based actions, such as controlling speed and load, start-stop of a machine, controlling the condition of bearing through controlling temperature and/or lubrication of a bearing especially in inaccessible areas. Based on the results from Diagnosis and Prediction System, and assessments of time to maintenance and probability of failure, a work order will be sent, e.g. for automatic adding a specific amount of grease in a specific bearing/nipple based on bearing condition and, Fig.1.
6. Reports, recommendations and work orders of maintenance manual work: Recommendations, warnings and report will also be sent to the user describing what has been done, why, when,

In order to conduct the above mentioned six tasks, CPS-Maint will consist the following units: Data gathering, Signal processing, Brain with intelligence, Database, Interfaces and Actuators. The interfaces between CPS-Maint and measuring/signal processing system from one side, and actuators from other sides are controlled by special APIs. Wireless communication is considered for CPS-Maint unless there is a technical obstacle. The data flow is considered to be controlled by WAN or LAN from the measuring object, e.g. a machine, to CPS-Maint database. Also, the diagnoses and prediction results and work orders from CPS-Maint to the actuators will be exported using WAN or LAN, Fig. 1.

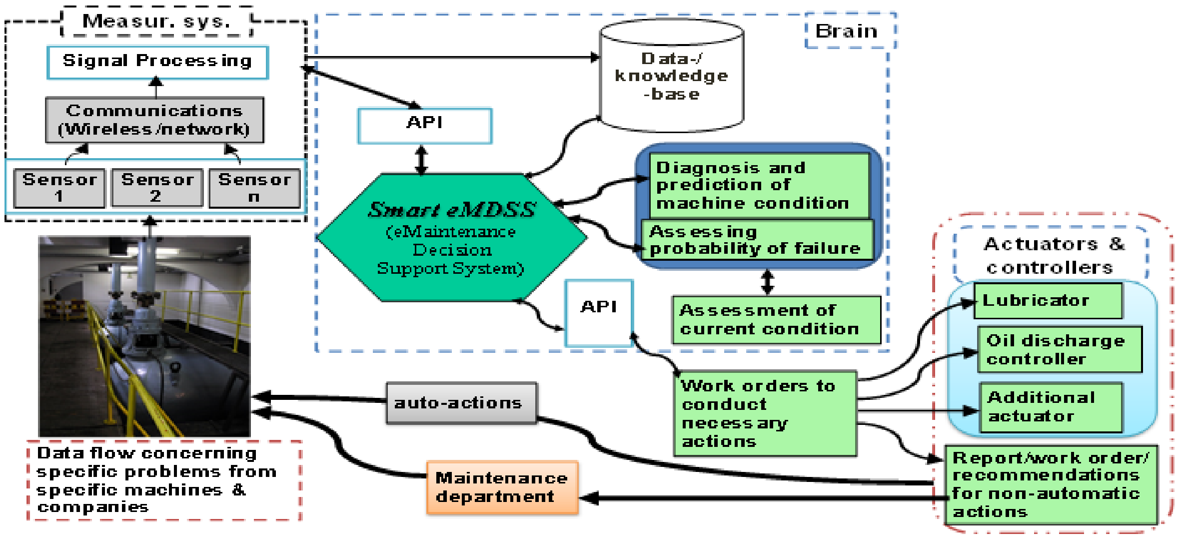

Fig.1. Intelligent CPS - Maint; data flow, diagnoses, prediction, assessments and self-healing actions

When wireless sensors and continuous measurement is used, CPS-Maint should be able to decide when to pick-up the measurement and how often. It will wake up the stand-by sensors for conducting a measurement in order to reduce energy consumption. Furthermore, when the actuator conducts a task, it will confirm the accomplishment of the mission by a report. This is why the APIs acquired double direction communication. The activities that are expected from Main-CPS are;

1. Data/measurements gathering according to the decided measuring frequency,
2. Data/information/spectrums analysis and diagnosis,
3. Prediction of condition of equipment/component,
4. Estimation of the time to conduct a maintenance action,
5. Optimizing and scheduling of maintenance action to reduce production stoppages,
6. Automatic conduction of specific maintenance actions.
7. Generating recommendations, work orders and diagnosis-prediction report

3. MODEL SIMULATION

Based on the developed model, a simulation using LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) software were developed. LabVIEW is a graphics-based software platform that is developed by the American National Instruments Company. It provides a visual platform for the development with minimum hardware requirement. Hence, the number of users of the program is growing in engineering applications (Guzel et al. 2016). LabVIEW contains two windows, the front panel (where the users interacts), which has all the input and the output and the block diagram. The block diagram, is the window responsible for the programming (Verma & Kumar 2016). Fig 2 and 3 show respectively the front panel and the block diagram panel of part of the program. The simulation consists of an injection molding machine that has a bearing monitored by CPS-Maint which contains vibration and temperature wireless sensors.

The signals coming from the sensors are analyzed by Brain Unit in order to detect any abnormality, diagnosis and prediction of the damage development. Consequently, a decision/recommendation for maintenance action and its time is generated and work report/order is sent to maintenance department and/or actuators, respectively. When the predetermined time comes, the Brain Unit triggers the actuator to conduct the required maintenance action. In order to activate the maintenance actions, we injected a damage (i.e. simulate an insufficient lubrication) and left the machine running at a high speed in order to speed the damage development process. At Brain Unit, when the CM values reached a predetermined level, the maintenance action is triggered. The work order sent to the maintenance department and an automatic release of lubrication started.

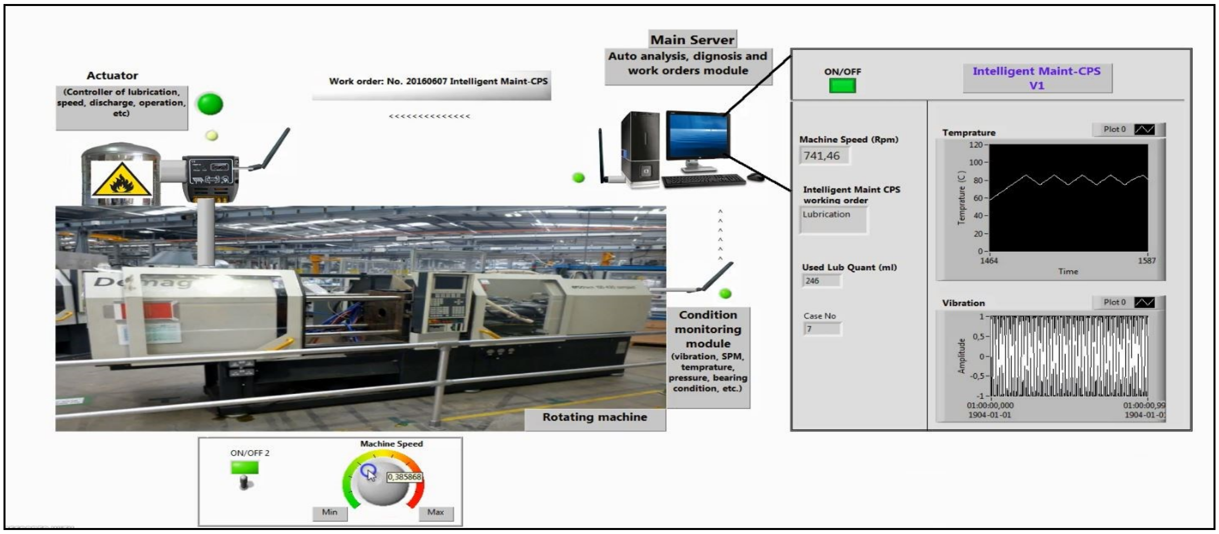

Fig. 2. Front panel of the Intelligent Maint-CPS simulation

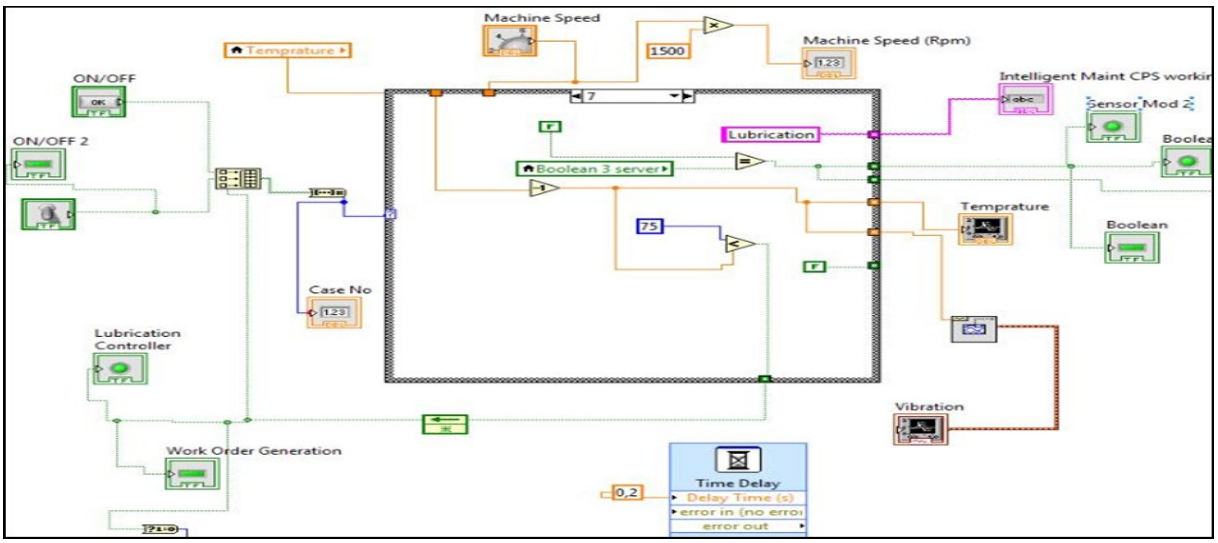

Fig. 3. Block diagram panel of the Intelligent CPS-Maint simulation.

The major results from the simulation were: The performance of the simulated model in the scenario showed a flow that the expected goals are accomplished and the required tasks are performed. There was no illogical process nor process conflict notified.

The idea of CPS-Maint with additional extensions will be applied on three demonstration companies (four machines) in PreCoM (EU-H2020-FoF 09, 2017-2020) and the application results will be reported in a new paper.

4. CONCLUSIONS

The major objective of the study is to propose a concept of novel approach to sustain production factory of today and future towards cost-effective automated and digitalized maintenance taking in consideration company business, production, quality, environment and energy consumption. CPS-Maint is characterized by high scalability, integrability, precision and cost-effectiveness to be applied on wider manufacturing systems. The data- and knowledgebase, DSS along with a continuous learning process are to facilitate rapid readjustment of the system with respect to the dynamic changes in the operating conditions, surroundings and applications. Flexibility, scalability and integrability enables communication of the system with personnel, manufacturing process IT-systems, such as MRPII, ERP, MES, machines and robots. This will facilitate its capability to be applied for monitoring different types of machines and manufacturing processes, and meet frequent changes in the operating conditions which will reduce maintenance time and cost, and prolong asset life length.

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