Initiating Industrie 4.0 by implementing Sensor Management – Improving operational availability

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Abstract. To stay competitive in the future, industrialists must be prepared to adopt the imminent changes and new technologies associated with Industrie 4.0. These changes apply equally to the field of maintenance, which is also developing quickly. Sensors, along with analyses and competence, are one of the most critical factors for Industrie 4.0 as they are the connectors between the digital and physical world. Utilization of these sensors within maintenance is a relatively unexplored field. Thus, the aim of this paper is to present a novel concept for ways sensor management can be linked to maintenance and thereby improve operational availability. The paper also presents an overview of sensor management and trends within maintenance.

Keywords: Sensor management, predictive maintenance, Industrie 4.0

1 Introduction

Sensors are the connecting elements between the digital and the physical world. Thus, sensor are one of the most critical factors for succeeding with Industrie 4.0, the Fourth Industrial Revolution [1]. The first Industrial Revolution started with the invention of Spinning Jenny in 1764, a multi-spindle spinning frame who was a game changer for the textile industry in England. Following, the world industry has gone through two other industrial revolutions, both of them causing a "make or break" situation for industrialists [13]. Implementing electricity into production processes and producing in high volumes were areas of focus in the early 20th century, and are the main characteristics of the second Industrial Revolution. Next, the introduction of electronics

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and computer technology for process automation and manufacturing significantly increased the level of performance for industrialists. This epoch is known as the third Industrial Revolution. Currently, humankind is on the threshold of the fourth Industrial Revolution, or “Industrie 4.0.” [20]. Fig. 1 gives an overview of the industrial revolutions.

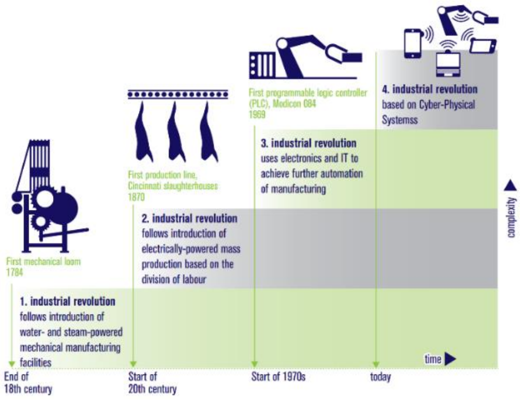

Fig. 1. The four stages of the Industrial Revolution [6].

Along with the imminent changes Industrie 4.0 and new technology is expected to cause for industrialists, an excellent opportunity rises for improving a company’s performance of maintenance. Throughout the years, the role of maintenance has evolved from the perception of being a hindrance for throughput and scheduling, to an opportunity for gaining a competitive edge by predicting and being one-step ahead of failures. Savings can be tremendous, as maintenance costs are one of the biggest contributors to the total operating costs for all manufacturing and production plants. In some industries, the maintenance cost can represent 15% to 40% of the costs of goods produced. For the years to come, and as a result of more automation and new technologies, maintenance will increasingly be more important for improving availability, product quality, fulfillment of safety requirements, and plant cost-effectiveness [3]. This development of maintenance is illustrated in Fig. 2, where four “maintenance revolutions” (the latest trend being predictive maintenance 4.0) shows the increased level of reliability, and need for data and statistics, as originally presented by PwC and Mainnovation [15].

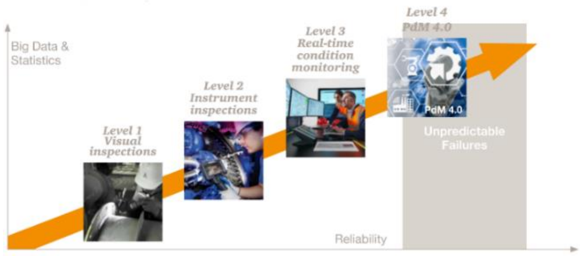

Fig. 2. Levels of maturity within predictive maintenance [15].

Within the field of maintenance, all superordinate maintenance systems for data interpretation, such as e-maintenance and computerized maintenance management system (CMMS), will be blind without the right sensors collecting data [1,12]. In years to come, data interpretation will be an essential enabler to follow the development of maintenance technologies, which underpins the need for sensor management [16]. Fig. 3 illustrates the progression of development within maintenance technologies.

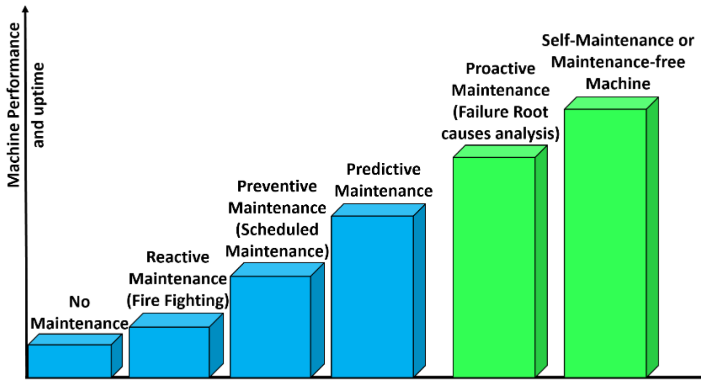

Fig. 3. Development of maintenance technologies [16].

A body of research is available on sensor management [4,7,14,17], but the research is aimed primarily at applications within military systems (tracking), robots, and radars. In [14] they also present that researchers and engineers have felt the need for conducting more work on sensor management, and [21] supports the unrealized potential for sensors as a maintenance-tool. This is also supported by [17], where it is claimed that the field of wireless sensor networks has matured, but the focus has been on environment monitoring, military and homeland security applications. Thus, the ways that sensor management can be connected to maintenance is a relatively unexplored field.

With this in mind, the aim of this paper is to present a novel concept for how sensor management can be linked to maintenance to improve operational availability; where operational availability is defined as: *"the probability that an item will be in an operable and committable state at the start of a mission when the mission is called for at any random point in time"* [5].

The structure of this article is as follows: Section 2 presents the state of the art within maintenance management and sensor management, followed by a proposal in Section 3 for a concept for a maintenance centered approach for sensor management. Section 4 provides a discussion, and lastly, Section 5 gives concluding remarks.

2 Maintenance Management and Sensor Management

2.1 Maintenance management and e-maintenance

To aid the maintenance management with the increased level of information and to have it available in real-time, and as support for decision-making, a computerized maintenance management system (CMMS) is required [18]. In addition to developing preventive maintenance schedules based on maintenance history, CMMS can also support condition-based maintenance (CBM). In CMMS, a CBM strategy will trigger a task when target values have been exceeded or not reached, such as on-line temperature measurements [10]. The triggering of the tasks can be based on more sophisticated decision criteria when implementing e-maintenance in the company strategy. In addition to monitoring the state of a system, it will be possible to apply predictive maintenance with failure prognostics built on specific degradation assessment algorithms and prognostics algorithms [12,19]. In more detail, e-maintenance, along with expert systems, offer maintenance support and tools such as intelligent actuation and measurement (IAM) [19], as well as failure analyses and maintenance documentation [12]. E-maintenance has also been addressed to be essential for prognostics and health management (PHM) [2], and implementing platforms based on a value-driven approach [11]. In particular, the notion smart sensor support several capabilities in e-maintenance:

- real-time data acquisition from the physical asset;
- data processing based on predefined algorithms;
- data transferring, and
- connection to networked environment

Although considered as a technological component in e-maintenance, application of sensors should also be included for management activities where e.g. strategy for connecting sensors to the physical asset is evaluated. Thus, there is a need for expanding smart sensors into sensor management.

2.2 Sensor Management – an overview

The term sensor management was first used in the context of automatic control of sensor systems in military aircrafts, where the goal was to control sensor resources to provide and present the most essential information (e.g., most critical threats/alerts) for the pilot. Later, sensor management was actively used within "active vision" for applications in robotics, in order to improve robotic vision systems. In recent years, the development of sensor and communications technologies has led to a rapid growth of interest within the field of sensor management, and different applications in other areas are continually being developed [4]. In [14] they claim the need for sensor management, and report the application of sensor management in several domains, and suggest that more research should be performed in the field. A recent literature review indicates that sensor management within the field of maintenance is a rather untouched area.

Sensor management is described in several ways in the literature. A more generic statement of sensor management is presented in [14], and goes as follows: *"to manage,* *co-ordinate and integrate the sensor usage to accomplish specific and often dynamic mission objectives."* In [7] they claim that sensor management can be treated as a: *"general strategy that controls sensing actions, including generating, prioritizing, and scheduling sensor selections and actions."* Additionally, another description of the term sensor management is given by [4]: *"control of the degrees of freedom in an agile sensor system to satisfy operational constraints and achieve operational objectives."* Based on the previous descriptions, the authors propose the following definition of sensor management within maintenance:

> *«Sensor management aims to optimize a configuration of sensors, with the goal of improving operational availability for a given system»*

Lastly, regarding sensor control, the following sensor management guidelines are important to take into consideration [1]:

1. What benefit shall the sensor application generate?
2. Are the measurements already known? Which ones shall be captured?
3. How much installation space and which interfaces are available for the sensor system?
4. To which ambient conditions is the sensor system exposed?
5. Which characteristics shall the measuring signal have for the planned data interpretation?
6. What is the consequence of a sensor system failure/malfunction?
7. What is the target quantity for implementing the sensor system?

These questions establish a baseline of parameters that define the data collection required for sensor management.

3 A maintenance centered approach for Sensor Management

In [18] they claim that utilizing data gathered to provide information and insight to maintenance engineers and managers to make optimal maintenance decisions has always been a challenging task. However, a company in the process industry has discovered a way to take advantage of the latest in sensor technology, namely wireless sensors for monitoring of equipment, where two major advantages is experienced. First, the sensors have a battery lifetime up to 15 years, with measurements taken every two seconds and transferred every two minutes (cloud or local storage). Second, they can measure parameters such as temperature (surface, air, liquid), humidity, light, open/closed function, signal transmitter (analog to digital), and pressure (vibration and laser distance are upcoming). Until now, experience shows several maintenance quick-wins by implementing these types of sensors, e.g.:

- Continuous measurement of equipment, which previously has been difficult/expensive to measure
- Easy access to data on smartphone/tablet/web-app
- Fast setup and an appealing user interface

- Adjustable control limits and alarm function ensure quick action when deviations occur, as notifications are directly sent to the maintenance personnel responsible for the given equipment
- Reduced time spent on preventive maintenance rounds
- Maintenance personnel take ownership of the sensors, and data, finding new areas for application, measurement points, and uses for troubleshooting

Sensor technology is continuously improving and becoming more available in terms of both cost and connectivity, and accessibility to data is seen as a foundation for Cyber-Physical Systems and Industrie 4.0 [8,9]. Thus, it is important to prepare organizations on how sensor systems can be implemented effectively to utilize their full potential in terms of maintenance. Fig. 4 presents a novel concept for sensor management applied to the maintenance function.

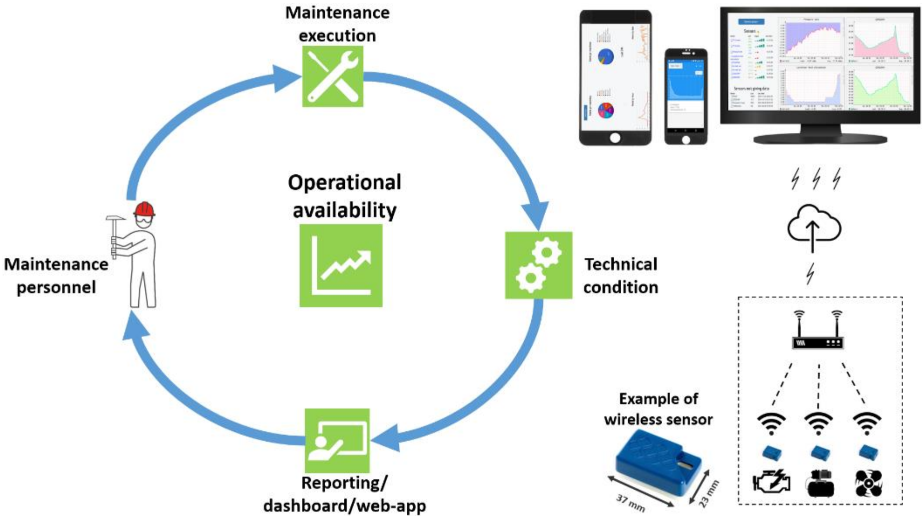

Fig. 4. Novel concept for sensor management within maintenance.

The proposed concept focuses on improving operational availability, where technical condition for a given equipment/system is evaluated based on data collected by mounted wireless sensors. By using cloud storage, technical condition, historical data and trends (along with notifications) are directly available on smartphones/tablets/web-apps. Adjustable control limits with an alarm function, which notifies maintenance personnel immediately when deviations occur, result in reduced time for initiating maintenance execution. The effect of the performed action can then directly be evaluated, by comparing historical data with the continuous stream of new measurements from the sensors. Summarized, the initial concept focuses on simplicity, and does not include advanced prediction analytics or decision support at this stage, but instead strives to maximize the value of the maintenance personnel's experience and knowledge.

4 Conclusion

This article has proposed a novel concept for how sensor management can be linked to maintenance to improve operational availability. The concept presents the flow between technical condition, reporting, maintenance personnel, maintenance execution, supported by data from sensors and the benefits of cloud storage alongside web-app for smartphones/tablets. The simplicity in this initial stage of the concept is expected to result in ease of implementation, and utilize maintenance personnel's experience and knowledge.

The importance of sensor management within maintenance is also discussed, as sensors are the connecting element between the digital and the physical world. The current advancements suggest that sensors and data will be essential to follow the latest trends in maintenance technologies, along with predictive maintenance, CMMS and e-maintenance.

In summary, additional research is needed to further develop the concept proposed in this paper, and discover ways this concept can adopt other technologies, such as condition assessment and diagnostics/prognostics. Case studies based on the concept and research in these areas are suggested for further work.

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