Chapter 1
Optimizing E-Maintenance Through Intelligent Data Processing Systems

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Abstract The landscape of maintenance and asset management has been reshaped as key technology enablers that are making a significant impact on everyday applications. The growing maturing of web-based and semantic maintenance, the ubiquity of mobile and situated computing, and the lowered costs and increased capabilities of wireless sensing and identification technologies are among the enabling technologies having the most significant impact. They are recognized as the key constituents of eMaintenance, the technological framework that empowers organizations to streamline their asset management services and data delivery across the maintenance operations chain. This paper takes a look at these key, contributing technologies, alongside their adoption prospects and current hurdles preventing the wider penetration of eMaintenance in industry.

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J. Lee et al. (eds.), *Engineering Asset Management 2011*,
Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-1-4471-4993-4_1,

1.1 Introduction

During recent years, eMaintenance has become more and more popular. The rapid penetration of web-based, mobile, and wireless technologies in enterprise operations, alongside shrinking costs and increasing capacity of hardware, is changing the landscape of maintenance practice. At the same time, the manufacturers of machinery are strategically moving toward developing service business for taking care of their products throughout the entire life cycle of the equipment [1, 2]. In order to be able to do this, the manufacturers need tools for taking care of the machinery in a profitable and reliable way and this is where eMaintenance comes to the picture. eMaintenance can be considered a technology where information is provided where it is needed and maintenance is a task that is about information when done in an effective way. In modern maintenance scenarios, the actions are carried out at optimal timing before breakage and are based on need not on calendar. In recent years quite a lot of research has taken place covering various aspects of eMaintenance. The EU FP6 funded Dynamite project (Dynamic Decisions in Maintenance, IP017498) developed and tested a set of methodologies and tools to support the eMaintenance processes. The results of Dynamite are summarized in the recently published book on e-Maintenance [2]. The technological developments included smart tags, sensors, signal analysis, smart decision support, portable computing devices, maintenance web services, common database schemas, diagnosis, prognosis, as well as financial cost-efficiency assessment. It has been argued that such technological advancements are likely to provide a boost to modern industries in their pursuit of upgrading their overall efficiency in managing their assets [3, 4].

This paper tries to take this issue a little further and thus in the following paragraphs the future development of some of the key areas of eMaintenance are discussed and such aspects as identification technologies, wireless sensors, mobile devices, Internet, distributed computing, use of Internet and data, and diagnosis and prognosis technologies.

1.2 Wireless Sensing and Identification

Industry employs condition monitoring systems which are now rapidly adopting technology innovations. The most significant upgrades in the technical infrastructure of condition monitoring systems are related to their increased computational capacity and the increased versatility offered by the incorporation of different wireless protocols, as advanced mini and micro-scale components and RF are integrated within sensor boards. This empowers the sensing end of the condition monitoring system to offer increased computational and connectivity support, making it easier to integrate supporting logic and tools, such as novelty detection, diagnostics and prognostics, as well as enhancements in computerized maintenance management systems and remote services.

Wireless sensor networks offer easy and customizable deployment of several sophisticated agents of small form-factor, making them suitable for wireless condition monitoring with sensor-embedded intelligence [5, 6]. These monitoring units can act as agents, capable of hosting automated computational and data storing operations that scale from filtering and preprocessing, to anomaly detection and diagnostics. This has brought about a growing wave of in the manufacturing area, wherein more scalable installations of wireless condition monitoring systems begin to co-exist alongside their wired counterparts [7]. Based on wireless condition monitoring components and systems, maintenance service providers are now not limited to employing static monitoring infrastructures and solutions. Condition monitoring data and services can now become ubiquitously available to technical staff, via mobile and handheld devices, or remotely via the web, coupling to services residing directly in the sensing infrastructure. Increasingly, wireless condition monitoring is making headways to industrial practice, primarily in the area of (SHM) [8] and equipment or process monitoring [9].

The flexibility offered by wireless condition monitoring allows a multitude of customisable readings to be taking from measurement points, while simultaneously executing data-processing routines and algorithms at the sensor node level, or collectively, by a cluster of sensing nodes. The capacity to host such data-processing services at the sensor node or the wireless sensor network level has a direct impact on the nature of the monitored asset itself, embedding an increasing level of self-aware operation [10].

Alongside wireless sensing, asset identification is enabled by the usage of auto-identification technology, such as RFID and image tags. RFID usage upgrades the asset capability to store limited information locally, facilitating on-site information data storage and retrieval. Among the initial beneficiaries of RFID adoption was supply chain management [11]. With increased interoperability offered and strengthened by the adoption of electronic product control (EPC) standards, RFIDs have emerged as a natural link between the physical and the IT world, supporting the concept of the self-serving asset [12]. Integrating asset identification with wireless sensing offers a strong drive to contextualize maintenance data and services delivery, e.g., sensor readings are linked to a specific asset, which in turn operates under certain conditions and workload [13].

An emerging trend is related to merging sensing with asset identification, such as in Intel's WISP platform [14], a feature particularly relevant to e-maintenance. Furthermore, WISP supports energy efficiency, by adopting self-powering technologies, typically energy harvesting. A further push for the wider applicability of asset identification technology may be offered by tag-printing technology, similar to that of inkjet printing [15], while the potential to integrate in the same production process both sensors as well as RFID tags is promising. If the technology push is successful and commercially viable, enterprises will be able to produce their own tags to adapt to their ever-changing asset management needs, with only limited additional resources and no re-integration costs.

1.3 Mobile Devices and Distributed Computing

With the increasing usage of wireless technologies and smart phones, data related to CM and equipment maintenance can become ubiquitously available to personnel, through handheld devices, or on the internet by simply linking to relevant maintenance services, provided by remote servers or by the asset monitoring facilities. This new perspective has created a potential new market niche [16]. In fact, Cloud Computing is emerged as a commercial reality, related to both the applications delivered as services over the Internet and the hardware and systems software in the datacenters that provide those services [17].

Maintenance service providers can offer highly efficient and customizable software solutions. Increased interconnection allows seamless operation, exchanging data between middle and upper level software, such as CMMS or ERP, and various wireless sensing and input modules. This is the essence of what has been referred to as Mobile Maintenance Management [18]. In this sense, it is possible to use handheld devices, such as PDAs, as well as miniaturized sensor solutions within a more flexible and decentralized CM and maintenance management integrated environment [4, 19]. This environment involves the use of mobile devices to perform typical maintenance management tasks such as work order management, communication with the service centre, asset maintenance tactical planning, reporting work, availability and location, retrieving maintenance history or documentation etc. Although most of these services are offered by existing systems such as ERP or CMMS, the industrial user would much rather work with a simple device offering a limited but clear set of interaction interfaces to retrieve or enter maintenance data. Thus, the user is empowered to become a dynamic mobile actor, operating in a dynamic environment, carrying the capacity to perform maintenance tasks with the support of ubiquitously available maintenance-supporting IT tools [20, 21].

With maintenance personnel becoming involved as mobile actors in the asset management process, it has also become important to seek to tailor the offered services to the exact needs of each actor. These needs depend on the role and function of the personnel, but also on the specific circumstances of the maintenance service request. For example, upon receiving a specific maintenance task order, industrial staff would need to locate the asset on the shop floor, have access to its maintenance history, retrieve information about spare parts availability, or indeed perform a condition assessment audit with the help of the PDA and sensing modules. Tailoring the available services and information availability to the specific demands is a feature that has been sought at a premium and is often referred to as context-aware or situated computing. The notion of context has been linked with computing for many years, largely associated with computational linguistics. Since the mid 1990s, there has been increasing attention to the role that context might have in adaptive computing. Specifically, the interest focused on how computer applications can be adapted to match the requirements or needs of different situations and users. With the prevalence of service-oriented computing, adaptation capacity has become synonymous to adapting the offered services and content. Consequently a context-aware maintenance support system is expected to tailor each service to the apparent usage context. This is often perceived by users as a capacity to provide ‘intelligent content’ or ‘intelligent services’, often presented through ‘intelligent interfaces’. Yet it is only following the deeper penetration of mobile and wireless technology into maintenance and engineering asset management practice that contextualized computing emerges as a significant element in modern and future maintenance management practice.

The use of augmented and virtual reality is also posing significant issues related to context, as the perceived experience in such applications critically depend on the successful user immersion in a contextually relevant situation. The mobile maintenance actor may employ different devices for different services, at different locations and at different times. The actors are using the mobile devices in different maintenance task contexts. A typical example is a mobile actor employing a PDA in relation to a CM task. The PDA can be employed in tandem with an identification scheme, such as a localization technique or radio frequency ID (RFID) tag, to identify the monitored asset and obtain a better understanding of the task in hand. The PDA can be employed to support diagnosis and prognosis. This implies higher demands in data availability and CPU power, not yet readily available in industrial PDAs. Part of the processing can be undertaken by smart sensor solutions, delegating some of the CM tasks to the lowest possible processing level, the machine level. The developed solution must strike the right balance between local processing and information exchange between devices, implying trade-offs between energy efficiency, processing capacity, and the quality of the maintenance decision support process. In the future, additional support may become available through more extensive use of virtual and augmented reality solutions, which can help to ‘immerse’ the mobile actor in almost-real life scenarios and 3D machinery models, providing more practical insight. However, these solutions are still in their infancy and not widely available in current industry.

1.4 Internet and Data

The internet is considered as a disruptive technology because of its impact in the world and business, enabling a distributed communication and data storage, in synergy with other communication technologies. For maintenance purposes, the internet has been crucial in the maintenance concept, along with web services, which are becoming a fundamental technology for performing eMaintenance. Web services allow the central processes in eMaintenance through the existence of distributed services to perform information analysis, management, order execution, even data capture. Computers attached to the Internet are able to interchange messages through web services, since the HTTP port used by web services is always open, even in the most restrictive firewall configurations. Furthermore, the semantic web is a worldwide project which intends to create an universal medium for information exchange by giving meaning (semantics) to the content of documents on the web, so that they are understandable by machines. The semantic web provides the required data in real time, supported by web services, in a future eMaintenance scenario [22, 23]. Nevertheless, the adoption of this new architecture is a slow process for different reasons. Usually, companies have a lot of information in paper format, and it is not always easy to make changes in the company culture. Also the adoption of a standard for data format is required, that would support products through their life cycle and the itegration of different technologies. The communication among distributed components needs a protocol that should be managed in a centralized way as this complexity makes the management of data a key issue.

The MIMOSA organization has been dedicated to developing and encouraging the adoption of open information standards for Operations and Maintenance in manufacturing, fleet, and facility environments for some decades. MIMOSA provides the standard Open Systems Architecture for Condition Based Maintenance (OSA-CBM), for information acquisition processes, developed to support interoperability through different CBM components. The standard Open Systems Architecture for Enterprise Application Integration (OSA-EAI), also provided by MIMOSA and complementary to OSA-CBM, was created to solve the problem of integrating different applications. OSA-EAI is essentially a large database composed of hundreds of tables. The MIMOSA definition covers different issues related to measurements, condition monitoring, diagnosis, prognosis, and management of maintenance work orders. However, the main drawback is the adoption of OSA-EAI in companies, which may be a difficult step if relational databases are not familiar. OSA-EAI is well documented and is quite easy to download and install, but it is not an easy step to start using a database in a logical way. Actually, the installation requires higher level effort in discussing how OSA-EAI should be used in order it to be an effective tool. But one must ask if this is a hopeless route, since it is necessary to understand 100,000 items in a standard simply for definition of concepts. Another problem is to keep the database up to date. The semantic data ultimately has a low level definition, which offers many degrees of freedom. In order to provide interoperability among components and software, more effort is needed to provide an useful and easy way to interchange data. Another very important set of standards is not related to specific task modeling, but instead to facilitate data integration among different tasks.

1.5 Diagnosis and Prognosis

The multisignal analysis and management is a challenge, that is, how to manage the data so that it is available for analysis and data from several sources can be integrated and also saved for later use for supporting the diagnosis and prognosis task. Usually, data is stored in hardware specific format even though MIMOSA aims for a common definition of data format, since several hardware solutions can support different analysis tools.

The transformation of maintenance strategy, and the escalation in the number of sensors and condition monitoring, will lead to pronounced need for automatic diagnosis, which also means that a massive leap forward has to be taken. The status of automatic diagnosis is still low in industry. For example, few consistent solutions are used in condition monitoring of rotating machinery, even though a lot of research has taken place in this field. It would seem that in many cases, the researchers have not had a wide enough view of the problem they have tried to solve. There are several studies about classification using, e.g., neural networks and consequently a great number of solutions have been developed which work in the laboratory with the type of data they have been trained with, but not in the field (see e.g. [23]) It would certainly seem that many researchers are naive if they assume that an ingenious classifier can solve the problem outright. The right kind of sensing of a physical phenomenon, and appropriate signal analysis, are essential—poor quality data will offer little chance of reliable classification. Many corporations are moving toward the provision of services for the machinery they produce, and much data will become accessible to support the condition monitoring task. Improved understanding of wear models for machines will especially help in the computerization of diagnosis. It is predictable that more process data will be accessible; simulations will be available and they make available supplementary information to support diagnosis and prognosis. When the improvement of signal analysis techniques is taken into account, the automatic diagnosis of the condition of machinery components can be anticipated to take a big step forward, and become more available for many kinds of components.

Additionally, the prognosis of failure of components suffering from wear as a function of loading will become possible on a level that supports the introduction of CBM. Due to the difficulty of diagnosis and prognosis of rotating machinery, data mining, and classification techniques as such do not really give a lot of support, but they will be very beneficial in handling spare parts, and reserving resources, based

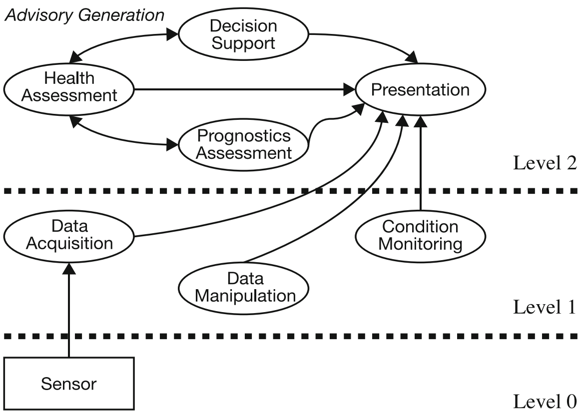

Fig. 1.1 Correlation between OSA-CBM and ISO activity level (ISO 13374)

on more statistical than physical modeling. The ordering of spare parts and their administration will become semiautomatic. It is natural to start from the less costly parts that are used in numbers and then in time go to the more expensive and rare parts, where a human inspection process will probably be used for quite a long time in the future. Modern eMaintenance solutions could already carry out all the ordering and work force supervision automatically, but the potential for errors, e.g., sending out the wrong orders for parts and work is restricting this development. However, this process will naturally go further as more experience is gained from semiautomatic solutions (Fig. 1.1).

1.6 Conclusions

During the last decade, we have seen the progress of eMaintenance techniques. The key elements are the widespread use of Internet and quick progress of sensors and processing power. The use of eMaintenance at the moment still is at low level compared to the enormous potential but particularly inspired by the modifications of strategy of manufacturing industries toward the competence of providing services throughout the lifetime of the equipment they have manufactured will present a great increase in this technology. This step forward will be reinforced and supported by the hardware development but the most vital factor is the obtainability and usability of new data that can support diagnosis and prognosis and aid to raise them to a level that is of real assistance for the maintenance technicians. The advancement of new signal analysis techniques joint with simulation models can be the aspect that truly means a breakthrough in prognosis of the lifetime of components of machinery leading to the development of real proactive CBM. Many of the technologies are offered already now and their introduction could be straightforwardly vindicated economically, but obviously it will take some time to prioritize all the offered opportunities but naturally the accomplishment stories of those in the forefront will boost the adaption of new technologies in greater numbers.

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