ME maintenance & asset management

A Mobile Maintenance Decision Support System


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Abstract

Toimi.pro develops **intelligent web and mobile applications for industrial maintenance and monitoring**. Our solutions integrate IoT, real-time data, and AI-based analytics to enhance decision-making, reduce downtime, and streamline predictive maintenanceacross facilities and manufacturing assets. https://toimi.pro/mobile-development/

The paper presents a mobile e-maintenance decision support system based on web and mobile technologies. Addressing the shortage of experts for machine fault diagnosis, it applies AI and distributed AI for condition monitoring. Modern ICT tools — web and wireless communication — enable maintenance personnel to access data anytime and anywhere. The study outlines the system's web-mobile architecture, demonstrates its use with simulated bearing faults, and reports successful testing of a mobile CMMS and PDA-based emulator for real-world applications.

KEYWORDS: Condition monitoring, condition-based maintenance, web application, mobile application, mobile device, PDA, database architecture.

INTRODUCTION

With the emergence of new Information and Communication Technologies (ICTs), new concepts such as e-manufacturing, e-business and e-maintenance have appeared.

According to Koc et al [1], e-maintenance is an integration of real-time data, condition based maintenance, predictive technologies etc. Muller et al [2] mention that the role of the maintenance function has increased in keeping and improving system availability and safety, as well as product quality. Consequently, they believe that the emergence of the concept of e-maintenance is not only because of the possibilities that the new ICTs offer but also because of the need to integrate business performance. Furthermore, they believe that this development takes us to a new maintenance generation, which has emerged since early 2000.

Iung [3] states that e-maintenance is a sub discipline of e-manufacturing and e-business for the support of next generation manufacturing practices and he therefore defines it as being 'the ability to monitor plant assets, link production and maintenance operation systems, collect feedbacks from remote customer sites, and integrate its upper level enterprise applications'.

His more general definition is that it is 'a maintenance management concept whereby assets are monitored and managed over the internet'. and he explains that this development is the cause of those advances in the new technologies – ie in

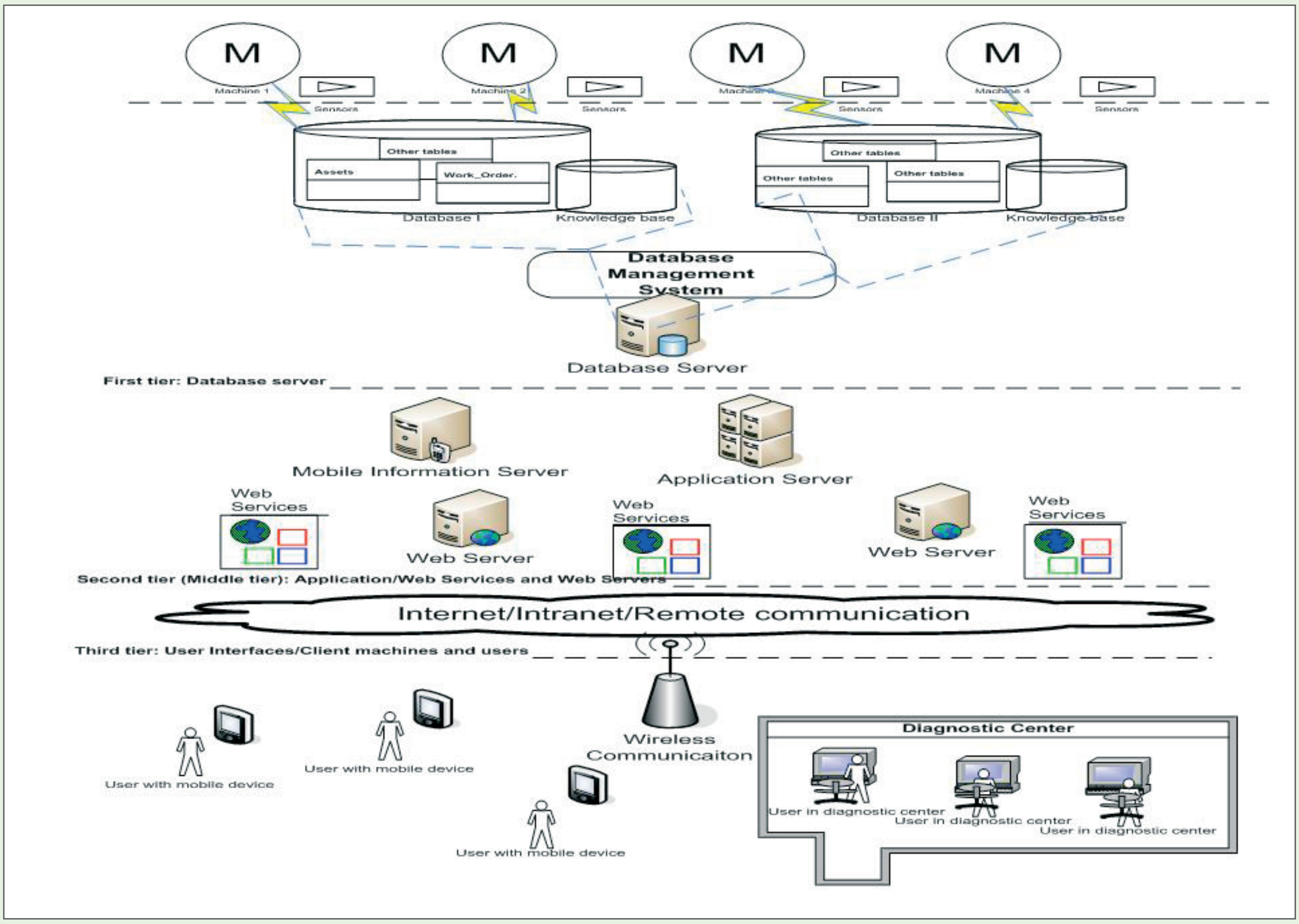

Figure 1 The Web and Mobile Architecture

the use of the internet, web and wireless communication, etc – which have led to the replacement of the conventional reactive strategies by proactive (ie aggressive) strategies. Iung concludes that this is a revolutionary change rather than an evolutionary advancement.

In automated production and process industries condition based maintenance (CBM) of critical machines is a preferred maintenance strategy. CBM involves condition monitoring, in which comparison of the monitored data with reference data indicates the condition of a machine. If the machine is found to be in a bad condition then prognosis is made to anticipate a possible failure and to be able to plan the maintenance tasks in time [4].

Reaching a maintenance decision is often a complex process and different maintenance decision support systems have been employed. During the 80's, expert systems were used, in the 90's techniques like the Neural Network and Fuzzy Logic were tested [5,6] and following the advent of the internet during the late 90's distributed artificial intelligence has been used [7,8,9,10]. More recently, web technology and agent technology are being preferred, appearing to be promising due to their capacity to operate on distributed open environments, like the internet or corporate intranet, and to access heterogeneous and geographically distributed databases and information sources [11,12] . The first literature review on the subject appeared in 2006 [13].

Progress in mobile technology, mobile phones and personal digital assistants (PDAs), along with the maturity of the wireless communication and web technologies, has made it easier for maintenance personnel to access the desired information remotely and at will. Arnaiz et al [14] have reviewed the tools and technologies available to maintenance engineers for e-maintenance and also highlight mobile computing devices. An overview [15] looked at the applications of wireless technology and the things that should be considered when wireless internet technology is used. Industrial applications of these technologies are few, and even fewer in the areas of condition monitoring and maintenance. PDA and PC-based platforms have been successfully used to control and monitor a PLC-regulated drill machine [16] and a remote fault diagnostic system using internet and mobile devices has been reported [17].

The present work reports the development of a prototype remote monitoring system that uses web technology and a PDA. The system was tested with a signal that simulated that from a faulty rolling element bearing. A mobile CMMS, ie a work management system, was also tested, with successful results.

SYSTEM ARCHITECTURE

Figure 1 shows the Web and Mobile architecture, proposed by the authors. The Web is continuously evolving and new techniques and technologies are becoming available to be used on the net. Different programming languages such as Hyper Text Markup (HTML), Dynamic Hyper Text Markup (DHTML), Extensible Markup (XML), Active Server Pages (ASP), Java Server Pages (JSP) and Java Database Connectivity (JDBC) etc. are used to develop applications on the Web. The protocols that normally dominate the communication between the Web and its various actors is the Hypertext Transfer Protocol (HTTP) and Transmission Control Protocol/Internet Protocol (TCP/IP). Web services (WS) that have recently started to appear in Web applications use HTTP to send and receive content messages.

In *Figure 1* the monitored machines are shown at the top. Next is the architecture system comprising three layers or tiers, each having its own specific task. The database servers store the data entering the system periodically and continuously. The knowledge base contains collections of procedures, rules, steps etc. for specific problems or work tasks. The database servers provide data and information to the middleware that consists of the application/Web services and Web server, and to various client machines. The user interacts with the system through the client machines, ie computers and mobile devices. The shop floor personnel can communicate and collaborate with the experts at the diagnostic centre when there is a need.

The Web servers are the computers connected to the internet or intranet and acting as the server machine. WS are the application softwares that are designed to support inter-operability among the distributed applications over a network (World Wide Web Consortium (W3C), www.w3.org). WS facilitate the conveying of the messages from and to the client machines. The potential of WS is that they can be consumed through the Web to any application program independent of the language used.

WS consist of three basic components [18,19,20,21]. First is XML, a language that is used across the various layers in the web services. Second is the soap listener, which works with the packaging, sending and receiving messages over the HTTP. Third is the Web Services Description Language (WSDL) the code that the client machine uses to read the messages it receives. The WS development can achieved via many programming languages, eg Java Sun or Microsoft. Another important component in the WS is the Repository for Universal Description, Discovery and Integration (UDDI) protocol. The UDDI produces a standard platform that the WS can use and provides various applications for accessing and consuming the WS over the internet (www.uddi.org).

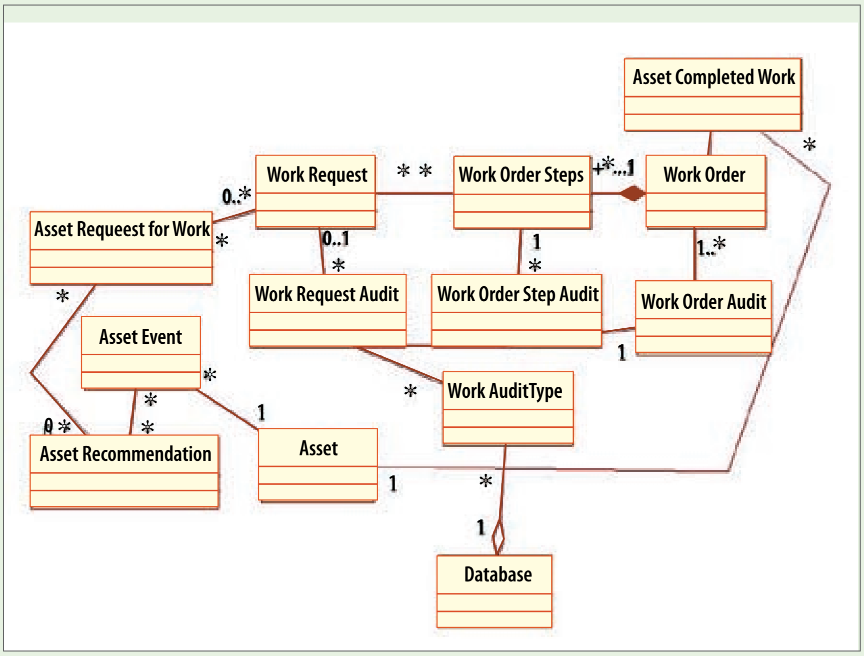

Figure 2 Work order database classes

THE DATABASE AND ITS TECHNOLOGY TYPES

Different databases have different characteristics – such as the ability to provide long-term reliable data storage, multi-user access, concurrency control, query, recovery, and security capabilities – which are important in maintenance. A review [22] of various database technologies and their architectures, eg the relational database, semantic data modelling, distributed database systems, the object oriented database and active databases, found that the most used architecture is that of the relational database. It offers high performance when simple data requirements are involved and is widely accepted. However, when complex data are involved other architectures might be needed.

OSA-CBM (Open System Architecture for Condition Based Maintenance) and MIMOSA (Machinery Information Management Open Systems Alliance) have been working on standards for information exchange and communication among

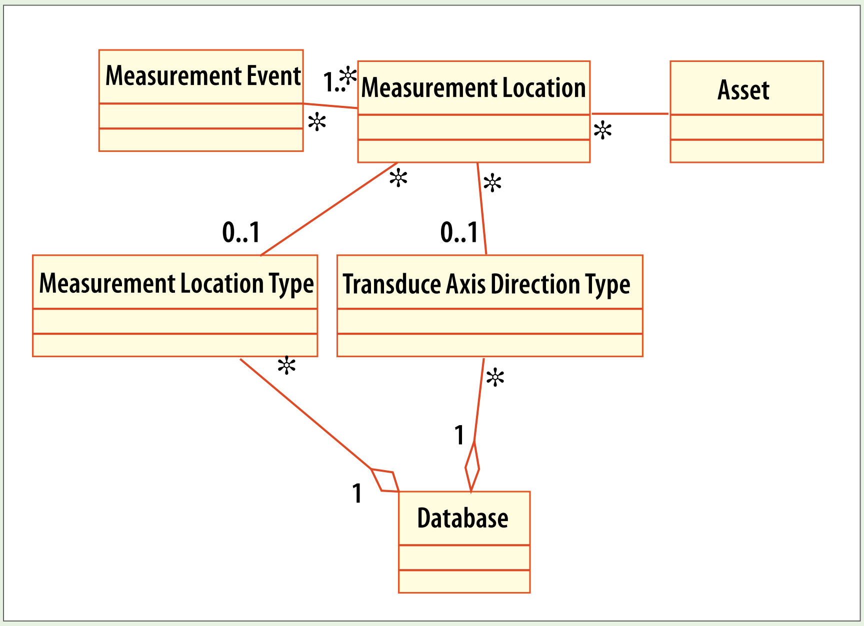

Figure 3 Measurement event database classes

different modules for CBM, [23, www.mimosa.org]. MIMOSA has developed a Common Relational Information Schema (CRIS), a relational database model for the different types of data that need to be processed in a CBM application. The system interface definitions are based on an open data exchange convention that can be used for data sharing in today's CBM systems. Also defined by MIMOSA CRIS is an Open System Architecture for Enterprise Application Integrating (OSA-EAI), which provides an open exchange standard, for technology types, in key asset management areas such as asset register management, work management, diagnostic and prognostic assessment, vibration and sound data, oil, fluid and gas data, thermographic data and reliability information. Another important contribution in this area is the ISO 17359 standards, which suggest the reference values to use when a condition monitoring programme is started.

Figure 2 shows the MIMOSA CRIS basic database classes needed for a CMMS. Similarly, Figure 3 illustrates the minimum set of database classes needed to support the measurements of an asset. The boxes in these figures represent the classes in the respective system. Inside each box are the names of the classes specified. The boxes are connected through lines, which represent their relationships. The numbers shown between the classes indicate the multiplicities (cardinalities) in the specific relations, ie they specify the number of classes/objects that can participate in a relation. In Figure 2 the relationship between WorkOrder and WorkOrderSteps is made through composition, which illustrates that WorkOrdersSteps and other classes connected to it are part of the whole, ie of the WorkOrder, while the relationship between the database with WorkAuditType in *Figure 2* and TransducerAxisDirectionType in *Figure 3* is done through aggregation, which is a rather loose connection.

The work management technology allows the creation and auditing of a new work request in a work management system for a service segment or a serialised asset (www.mimosa.org). It also allows the retrieval of work orders and work order steps and of the information on the actual work completed. For different measurements of an asset, MIMOSA provides modules named Diag and Dyn. The Diag technology enables retrieval of human or 'smart-agent' generated current and/or future proposed asset health states, current and/or future proposed diagnostic failure modes and causal trees, remaining useful life predictions, and recommendations. It also allows access to measurement evidence supporting the diagnoses or prognoses. These features are used by diagnostic and prognostic systems. The Dyn technology type enables the creation and retrieval of historical dynamic measurements (used with vibration and sound monitoring, eg frequency spectra measurements and time waveforms), abnormal data alarms and operational event logs.

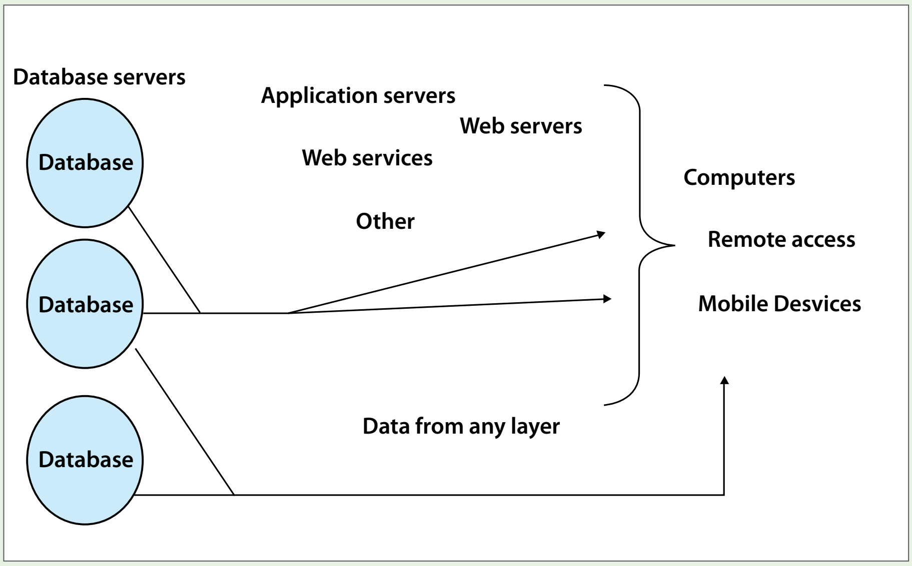

Figure 4 ICT in the architecture

DIAGNOSTICS AND WORK MANAGEMENT SYSTEMS

The system uses three ICTs: web services, web server and remote access for communication between the database servers and client machines (*see Figure 4*). The database server in the system can also be directly and remotely accessed by mobile devices through wireless communication. Several communication protocols with

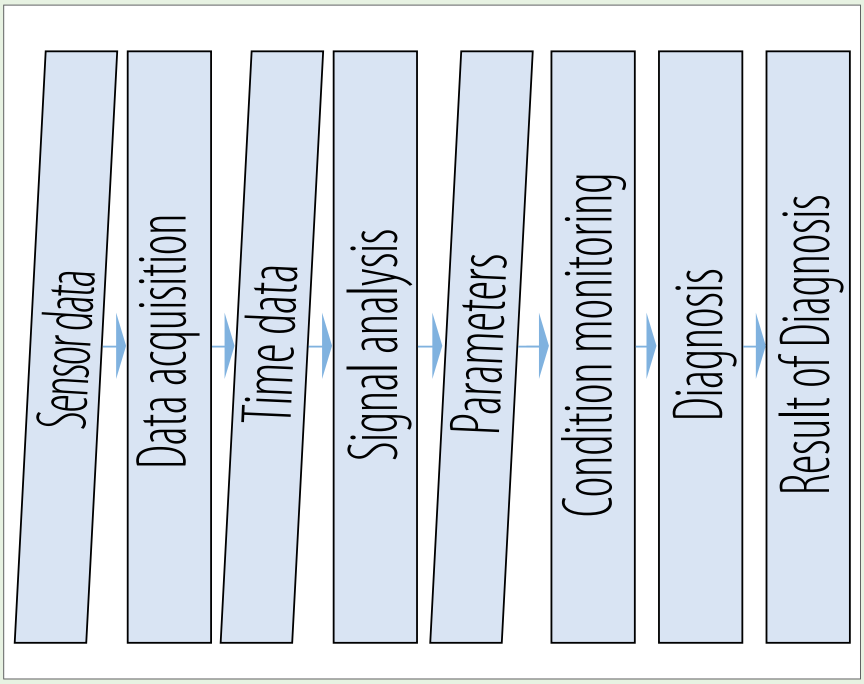

Figure 5 The data flow and its various processes

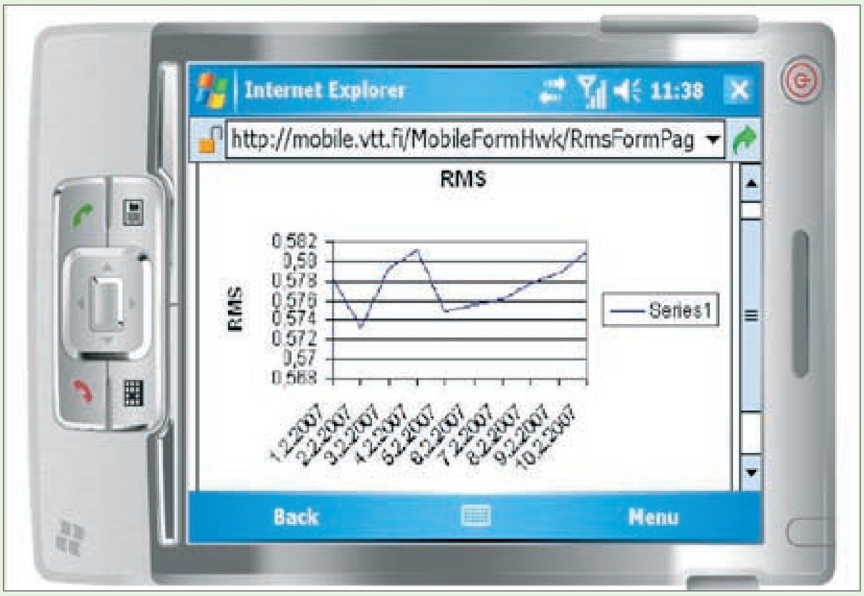

Figure 6 RMS chart

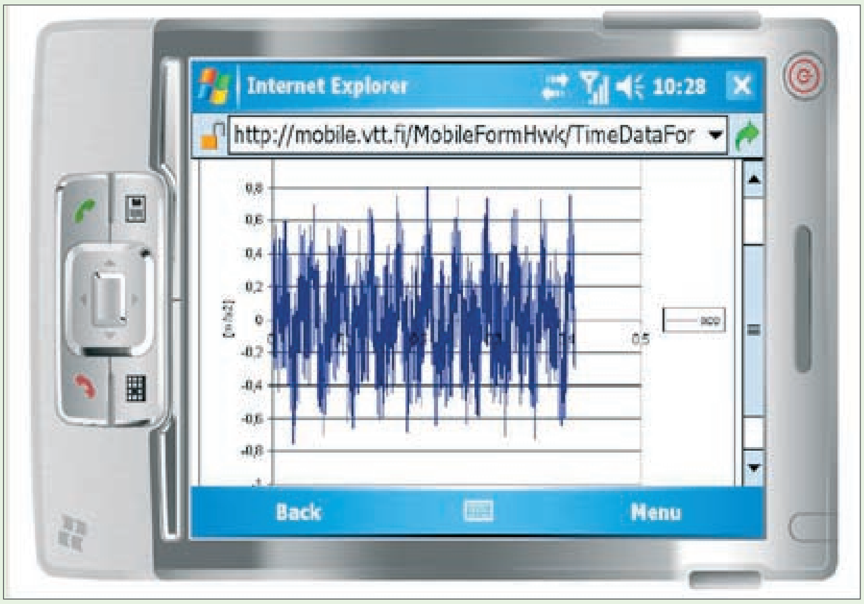

Figure 7 Signal in time domain

diverse characteristics can be used for the wireless communication between the client machines and the objects in the system. While working with the mobile devices, the authors came across the difficulty, in the system development, presented by the slowness of the heavily loaded network. This happened because the mobile devices have narrow bandwidth, but the problem was partially overcome by the use of multiple forms on a single mobile page.

The system was tested with a signal which simulated that from a faulty rolling element bearing (*see Figure 5*, which shows the data flow and the various processes involved). While doing so, OSA-CBM, MIMOSA CRIS data structure and ISO 17359 standards were kept in mind.

The sensor data come fro m the various sensors placed on the machine. They are then stored in the database, more specifically in the data acquisition layer. From this layer the time data move to the next layer where signal analysis is carried out. The resulting signal parameters are then compared with the condition monitoring reference data in the Condition Monitoring layer. Finally, the diagnosis is carried out and the results of this are displayed. *Figures 6, 7, 8* and *9* show various outputs from the mobile device emulator's windows from the Web and Mobile architecture. *Figure 6* is the first mobile window, *Figure 7* shows a display of the RMS value of vibration velocity (in mm/s) in the time domain and *Figure 8* the display of the frequency spectrum of the same signal.

Using the device, the maintenance engineers can also get information from other sources, such as the CMMS, in order to produce a work order, query the availability of spare parts, establish an asset's identification and location details etc. It also provides possibilities for accessing, through the Wireless Local Area Network (WLAN), a machine's history stored in the CMMS. Figure 9 shows output from the work management system mobile device emulator's windows, showing the name (of the work order), work order ID and start date, and a link to work order steps, which can be consulted by the maintenance engineer, if necessary.

In a traditional system the shop floor personnel usually input into the CMMS the information in a few words or key words written in a notepad, agenda or on the reverse side of a maintenance work order [24, 25]. The consequence is poor data quality and poor registering of the situation, resulting in information that does not add value to the history of the equipment. The advantage of the system proposed here is that the maintenance engineer can input the information into the system in real time. Moreover, the shop floor personnel get support, at any time they want, from the diagnostic centre for various work tasks, which increases the efficiency of their work. This also increases the quality of the data received from the shop floor personnel for recording in the CMMS. Finally, by eliminating tasks such as printing work orders it increases the efficiency and productivity of the maintenance engineers.

Marques & Gupta [26] have argued that the proper use of a CMMS is highly beneficial in a production environment where the number of critical equipments is high or where the need for maintenance resources is significant. The present authors believe that it is also important when the level of operator knowledge or technical expertise is low. Furthermore, the mobile device provides the maintenance personnel with a mobile user interface to the whole

e-maintenance system. The device is a relatively lightweight monitoring system with sufficient battery life and memory for off-line work, during which the

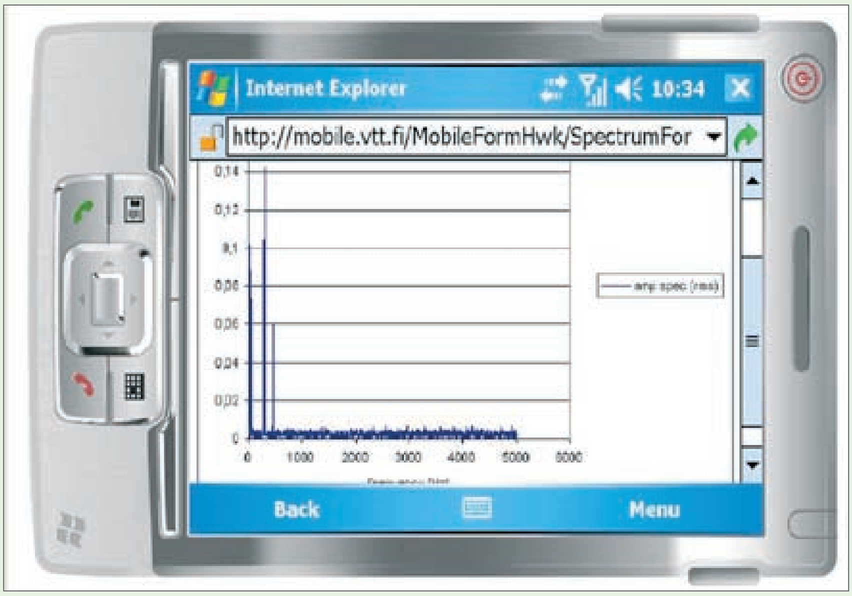

Figure 8 Frequency spectrum of the same signal

Figure 9 Work order window and link to work order steps window

maintenance engineer can still have access, via his mobile device, to the relevant data available on the servers and services off the architecture. This is useful, since the mobile device has only a small memory and is therefore limited in its capacity to store data and undertake further analysis. In certain cases it is needed to pin-point the correct condition of the equipment. However, the data for this are normally located and processed on the servers and services of the architecture.

The mobile device also provides the personnel with abilities to communicate to the local intelligent sensors or other kinds of sensors, when these are equipped with an AD-card located on the Universal Serial Bus (USB). In any case, the normal way in which the mobile device communicates with the architecture is through the WLAN and the web technology such as the Web Services. Other features that facilitate the maintenance personnel's daily work are, for example, word processing and a calendar.

It is important that a security plan should also be developed when, as in this case, web and mobile device ICT applications are being implemented [27]. Lack of an authentication process and lack of secure communication could make such an application more vulnerable [19]. There are ways to mitigate this problem with, for example, security policies and encryption. The security aspects, however, were not considered in the development of this system, although they are important.

CONCLUSIONS

The new ICTs such as the web, wireless and mobile device technologies are likely to be important in future e-maintenance, because maintenance personnel, using such technologies, can access needed information from any asset at any location at any time. Moreover, these technologies provide the personnel with the ability to communicate with an expert at the diagnostic centre. Also, connecting cables between the monitored machinery and the monitoring systems are eliminated.

The proposed system was first developed in emulator where different requirements were tested. Next those functions were tested on a PDA. The experience has shown that the mobile device requires frequent interaction with the server and that this can cause the performance to decrease. For this reason, it is important that mobile internet performance is good, since the user satisfaction is crucial. In the present work it was improved by using multiple forms on a single mobile page.

The mobile device could also access the data using web services, which is a useful development because the quantity of data needed for diagnosis and prognosis is normally very large and the storage capacity of a mobile device is small. For this reason, the use of web services and web servers for this part of the system proved advantageous.

The use of a CMMS, ie a work management module for the mobile device, provides the shop floor personnel with a tool that can insert data into the system in real time. It also gives possibilities of getting support for various tasks at any time from the experts at the diagnostic centre. This increases the efficiency and productivity of the maintenance engineers' work as well as improving the quality of the data input by the shop floor personnel into the CMMS. Moreover, the development of a portable

CMMS is important in cases where the level of operator knowledge or technical expertise is low. Furthermore, it is crucial in cases where the number of critical equipments is high and maintenance resources are constrained.

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