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ABSTRACT

*The paper reports the development of an e-monitoring and maintenance system based on web technology and mobile device, PDA. Rarity of experts led to the application of artificial intelligence and later, distributed artificial intelligence for condition monitoring and diagnosis of machine condition. Recently, web technology along with wireless communication is emerging as a potent tool in maintenance. It facilitates obtaining of the desired information by the relevant personnel at any time wherever he may be. The paper first describes the web and mobile architecture that formed the basis of the system and ICT tools used to communicate among the different layers in the architecture/system and its various client machines. It is followed by the demonstration of the use of the system with a faulty bearing simulated signal. A mobile emulator was used to perf*ect *the system for different requirements and the same was then tested on the PDA.*

INTRODUCTION

The basis of condition based maintenance is condition monitoring. It involves the acquisition of data, processing, analysis, interpretation and extracting useful information from it. It provides the maintenance personnel with the needed resources to identify a deviation from predetermined values. In the case of a deviation normally, diagnosis is done to determine the cause of it. Finally, a decision, regarding when and what maintenance tasks are to be performed, is taken. The prognosis is done to foresee a failure as early as possible and be able to plan the maintenance task in advance, (Jantunen, 2003). The decision support systems that have been used to help maintenance department to address this matter have changed and developed over time. In the 1980s, expert system was used and in the 1990s various techniques like the Neural Network and Fuzzy Logic were used in condition monitoring (Warwick, et al., 1997; Wang, 2003). Distributed artificial intelligence has also been used in condition monitoring after the advent of Internet during the late 1990s (Rao, et al., 1996; Rao, et al., 1998a; Rao, et al., 1998b; Reichard, et al., 2000). In this process recently, web technology and agent technology have started to appear in maintenance and condition monitoring. First review on the subject appeared in 2006 (Campos & Prakash, 2006). These technologies got wider acceptance because of the agents' capability to operate on distributed open environment like the Internet or corporate Intranet and access heterogeneous and geographically distributed databases and information sources (Sycara, 1998; Feng, et al., 2004). The developments in mobile technology, mobile phones and personal digital assistants (PDAs) in conjunction with the maturity of the wireless communication and web technologies have made it easier for the maintenance personnel to access the desired information remotely and at will. As such, the enterprises that choose to use these technologies are to gain competitive edge in the market. Arnaiz et al. 2006 provide an outline of the enabled tools and technologies available to the maintenance engineer, i.e. when e-maintenance is applied. They also provide an overview of mobile computing devices. Piggin and Brandt (2006) give an overview of the applications of wireless technology and also things to consider when implementing wireless internet for industrial application. Industrial applications of these technologies are few and even less in condition monitoring and maintenance. Yao, et al. (2005) made successful attempt to use PDA and PC-based platforms to control and monitor a PLC (programmable logic controller) controlled manufacturing system, namely, a drill machine. Wang, et al. (2007) report a remote fault diagnostic system using Internet and mobile devices. The present work reports the development of a remote monitoring system that uses Internet and mobile device, PDA. The approach to build the system was prototype approach. The system was tested with the simulated signal of a faulty rolling element bearing.

THE WEB AND MOBILE ARCHITECTURE

The web technology, i.e. Internet and Intranet, is continuously evolving and offering various techniques to utilise the application software's that run on the net. Intranet uses Web technology to create and share knowledge within an enterprise only. The Web consists of applications that are developed in different programming languages such as Hyper Text Markup Language (HTML), Dynamic Hyper Text Markup Language (DHTML), Extensible Markup Language (XML), Active Server Pages (ASP), Java Server Pages (JSP) and Java Database Connectivity (JDBC) etc. The protocol that normally dominates the communication between the Web and its various actors is the Hypertext Transfer Protocol (HTTP) and Transmission Control Protocol/Internet Protocol (TCP/IP). Recently, Web services (WS) started to appear in Web applications. They also use HTTP to send and receive content messages.

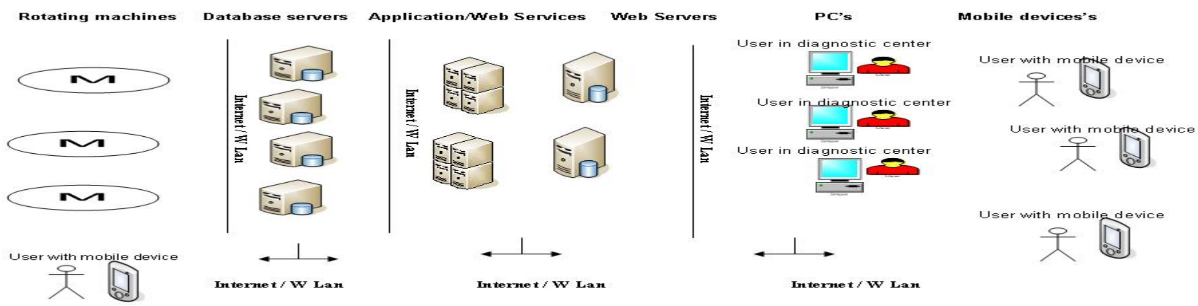

Figure 1: The Web and Mobile Architecture.

Figure 1, illustrates the proposed Web and Mobile architecture. In the left there are rotating machines. Next is the proposed three tier web and mobile architecture system. Each tier has its own specific task. The database servers store the data entering the system. They 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, i.e. computers and mobile devices. 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 interoperability among the distributed applications over a network (World Wide Web Consortium (W3C), www.w3.org). WS facilitates 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. They consist of three basic components (Newcomer, 2002; Meyne & Davis, 2002; Lee, et al., 2003; Venkatraman, 2004). First is XML. It is a language that is used across the various layers in the web services. The second is the soap listener. It works with packaging, sending and receiving messages over the HTTP. The third component is the Web Services Description Language (WSDL) the code that the client machine uses to read the messages it receives. The WS development can be done with many programming languages like from Java Sun or Microsoft. Other 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 provide various applications to find access and consume the WS over the internet (www.uddi.org).

THE DATA AND SYSTEM ARCHITECTURE

Databases are characterised of various factors such as their ability to provide long-term reliable data storage, multi-user access, concurrency control, query, recovery, and security capabilities. In maintenance are these important factors because of the need of for example gathering and storing data for the purpose of monitoring the machines' health. The database technologies have been changing over time and a review is available, Du and Wolfe (1997). The review goes through the database architectures such as relational database, semantic data modelling, distributed database systems, object oriented database and active databases. They mention that the most used is the relational database architecture. It has high performance when simple data requirements are involved and it has been widely accepted. However, other database architectures may be needed when complex data is used. The OSA-CBM (Open System Architecture for Condition Based Maintenance) and MIMOSA (Machinery Information Management Open Systems Alliance) are two organisations, which have been active in developing standards for information exchange and communication among different modules for CBM, [Thurston, 2001, www.mimosa.org,]. The OSA-CBM has been partly funded by the navy through a Dust (Dual Use Science and Technology) program [Thurston, 2001, www.osacbm.org]. There were various participants from industrial, commercial and military applications of CBM technology such as Boeing, Caterpillar, Rockwell Automation, Rockwell Science Center, Newport News, and Oceana Sensor Technologies. MIMOSA developed a Common Relational Information Schema (CRIS). It is a relational database model for different data types that need to be processed in CBM application. The system interfaces have been defined according to the database schema based on CRIS. The interfaces' definitions developed by MIMOSA are an open data exchange convention to use for data sharing in today's CBM systems. Other important contribution in this area is the ISO 17359 standards, which specifies the reference values to consider when a condition monitoring programme is implemented like for example standards for vibration monitoring and analysis. These were taken into consideration while developing the system.

DEVELOPMENT OF THE SYSTEM

The system used the three Information and communication technologies (ICT); the web services, the web server and the remote access for the communication between the database servers and client machines (Fig 2). Database server in the system can also be directly and remotely accessed by mobile devices. This is done via a wireless communication. There are various communication protocols having different characteristics for the wireless communication between the client machines and the objects in the system. The Mobile devices, in normal cases, have narrow bandwidth. If interaction with the servers is too frequent, the network gets heavily loaded and slows down. This problem was partially overcome in the development process through the use of multiple forms on a single mobile page.

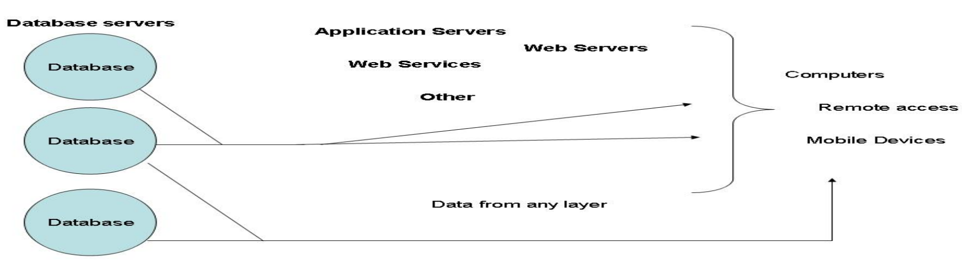

Figure 2: ICT in the architecture.

The system was then tested with the simulated signal from a rolling element bearing. The data flow and the various processes involved are illustrated in Figure 3. While doing so OSA-CBM, Mimosa Cris data structure and ISO 17359 standards were taken onto consideration.

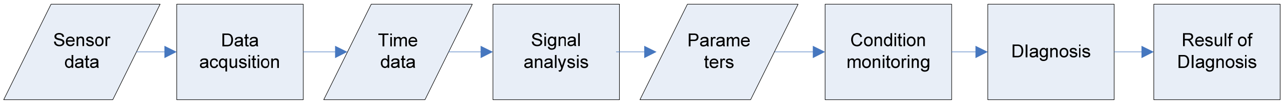

Figure 3: The data flow and its various processes.

In Figure 3, the sensor data is gathered from the various sensors in the machine. They are next stored in the database, more specific in the data acquisition layer. From the data acquisition layer are relevant time data sent to next layer where the signal analysis is taken place. The results of the signal analysis, illustrated in some parameters are compared with condition monitoring standards in the Condition Monitoring layer. Finally a diagnosis done and a decision is taken. The results of the diagnosis are displayed next. The Figures 4 to 6 below show various outputs from the mobile device emulator's windows from the Web and Mobile architecture. Figure 4 is the first mobile window and it illustrates the RMS value of vibration velocity in mm/s on different dates.

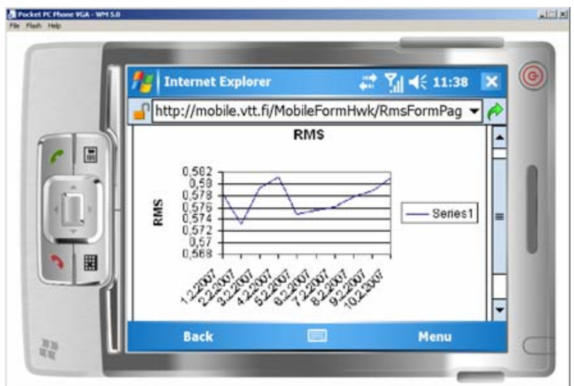

Figure 4: RMS chart.

Figure 5 shows RMS value of vibration velocity in mm/s in time domain and Fig.6, the frequency spectrum of the same signal.

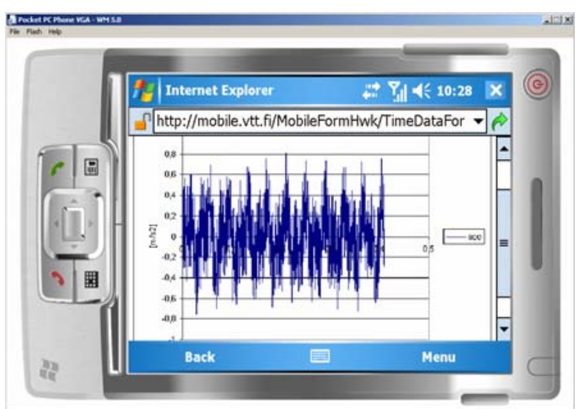

Figure 5: Signal in time domain.

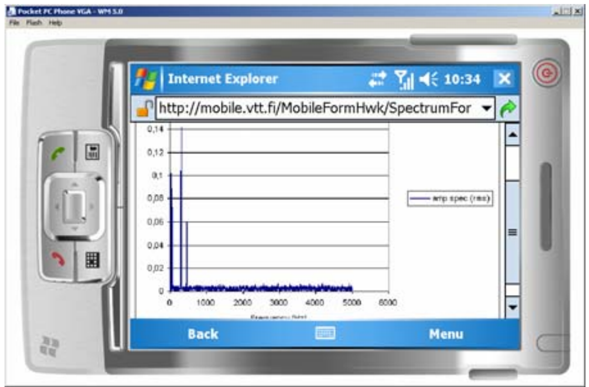

Figure 6: Frequency spectrum of the same signal.

As mentioned earlier the system was developed using a mobile emulator. Different requirements were tested here. After the satisfactory results were obtained the functions were tested on the mobile device, PDA. Figures 7-8 show outputs on a PDA window. Figure 7 shows the table with RMS values of vibration velocity in mm/s along with its date. The user can add, change, delete or update the values. The user has the possibility to scroll the mobile page up or down to access the links to other pages containing other tables or graphs such as the RMS Chart, in time data domain or frequency domain etc.

Figure 7: Date wise vibration values in tabular form and access to other links.

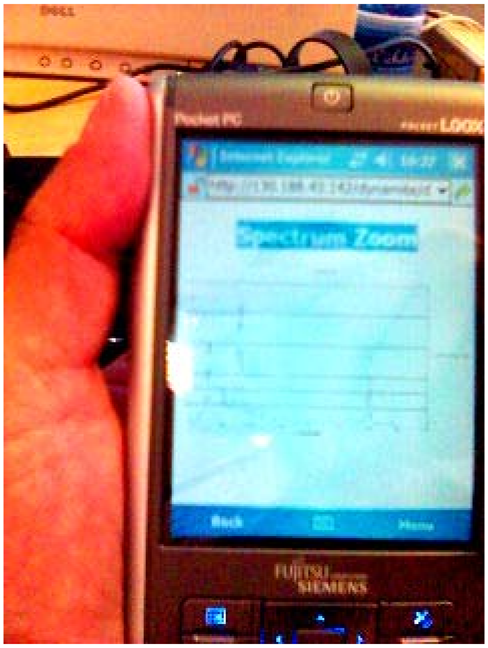

Figure 8: Zoomed frequency spectrum of the vibration signal.

Security factors should be considered when developing applications with ICT, in this case, web and mobile device applications. For this reason, it is also important to develop a security plan based on security issues and threats for the specific applications in hand (Bidgoli, 2003). The factors that make web and mobile devices more vulnerable are the cases of lack in an authentication process and lack of secure communication (Meyne & Davis, 2002). There are ways to decrease these factors with for example security policies and encryption. The security aspects, however were not considered in the development of the system, nevertheless, they are important.

The mobile device provides the maintenance personnel with a mobile user interface of the whole e-maintenance system. The device is a relatively lightweight monitoring system with long battery life capacity and memory that can be used for offline work. The maintenance engineers can also, through the device, get information from other sources such as the Computerized Maintenance Management System (CMMS) to be able to make a work order or see the availability of spare parts. It provides also possibilities to access, if needed, the history of the machine stored in the CMMS through the Wireless Local Area Network (WLAN).

Maintenance engineer while working offline but using his mobile device can still have access to the relevant data available on the servers and services off the architecture. This is useful since the mobile device has a small memory to store data and for further analysis. In certain cases it is needed to pinpoint the right condition of the equipment. However, the data is normally located and processed on the servers and services off the architecture. The mobile device provides also the personnel with abilities to communicate to the local intelligent sensors or other kind of sensors. It is possible when sensors 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 the personnel can use are, for example, the calendar and the word processing, which facilitates the maintenance personnel daily work.

CONCLUSIONS

The wireless technology seems to be an important factor in future maintenance. This is due to the elimination of connecting cables between the monitored machine/equipment and monitoring systems. The system was first developed in emulator where different requirements were tested. Next those functions were tested on PDA. The experience shows that it is normal that the mobile device requires frequent interaction with the server and this can cause the performance to decrease. For this reason, it is important that mobile internet performance is high since the user satisfaction is crucial. In the present work the performance was improved with the use of multiple forms on a single mobile page. The mobile device could also access the data using Web services. It is a useful development as the data needed for diagnosis and prognosis are normally huge in amount and the storage capacity of a mobile device is small. For this reason, the use of Web services for this part of the system was a good approach to take. In this way the load on the server also decreases and it helps to improve the performance of the Web and wireless communication. Finally, maintenance personnel can remotely monitor the health of an equipment that may be located geographically any where. The capacity of the wireless network used is the only limiting factor.

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