Ship machinery and equipment wireless condition monitoring system

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ABSTRACT: Condition based maintenance (CBM) is a maintenance approach that has been proven to provide significant reduction in maintenance cost and associated risk. Several industries such as aerospace and power generation have incorporated CBM and have been driving the developments in progressively better diagnostic and prognostic maintenance management. Other benefits that can be linked with appropriate use of CBM include better management of the operational characteristics of the vessel, reduction of emissions and energy efficiency. However in the maritime industry this is not the case. Less than 2% of the global fleet of vessels is utilising CBM (Shorten, 2012). This can be associated with several factors that inhibit the implementation of CBM in vessels. The most important of those are the cost of installation, the capital investment in training staff and the lack of trust in the prediction capabilities of the technology. This paper presents a novel method based on wireless data transmission which can demonstrate reduced installation costs. Moreover, as part of the INCASS (Inspection Capabilities for Enhanced Ship Safety) EU FP7 project, this paper presents a novel decision support system (DSS) solution that can be used onboard a ship with minimal initial training. The reliable user friendly graphical interface (GUI) developed in Java language provides relevant and on-time information for maintenance decision support. The combination of the developed hardware and software give a complete solution that can be applied to vessels while minimising investment costs and training.

KEYWORDS: Wireless sensors; Condition monitoring; Condition based maintenance; Decision support system

1 INTRODUCTION

Maintenance is mandatory for vessels to comply with international and national regulation (IMO, 1993a) as well as in order to meet the safety and environmental protection requirements including guidelines for emissions (SOLAS, 1974, MEPC, 2011). Finally, international regulations mandate inspections and surveys to be undertaken regularly and records maintained on the condition of each operating vessel (IMO, 1993b).

Through the above the operating company of the ship is responsible for identifying the appropriate method for maintaining the condition of the vessel, recording activities relevant to maintenance and utilising the mandatory Planned Maintenance System (PMS) (IACS, 2014). As a result most of the operators/owners tend to comply with the requirements through minimal implementation of the PMS system, paper based records and visual inspections. This can be associated with potential risk compared to other industries and increased accident/incident rates reported over the past few years (ECSA, 2013, DNV GL, 2014, EMSA, 2015).

Condition based maintenance (CBM) is more advanced strategy that relies on Condition Monitoring (CM) for diagnosis of faults and reduction of failures in machinery and equipment (Nemarich et al., 1990, Mechefske, 2005, Schwabacher, 2005). The method can reduce risk, increase safety and if utilised appropriately increase vessel performance and efficiency while assisting in reducing emissions throughout the life-time of its operation (Takata et al., 2004, Diakaki et al., 2015). However, there has been a slow uptake of this technology in the shipping industry. In 2012 according to a report for Lloyd's Register, Shorten (2012) supports that only 2% of the global fleet uses CBM in conjunction with PMS for better asset management, spare part ordering and improved condition of class.

The reasons for this can be associated with low confidence in the technology, security and confidentiality of data, training requirements and initial capital investment (Clarke et al., 2006, DNV GL, 2014, Latarche, 2015). Most importantly however, the benefit of CBM is not immediately identifiable for management and thus the return of investment is obscured (Shin & Jun, 2015).

On the other hand, the incorporation of CM, CBM and even Reliability Centred Maintenance (RCM) is extensive in other industries such as aviation and power generation. In those cases as well as in naval applications the reduction of maintenance associated costs is well documented (De Giovanni & Esposito Vinzi, 2014, Eker et al., 2015, Kara et al., 2015, Haque et al., 2015, The British Institute of Non-Destructive Testing, 2015, Lees, 2015, de Azevedo et al., 2016, MoD, 2006). Moreover methods of maintenance management have been developed for the prioritisation of maintenance tasks and decision support such as fuzzy multiple attributive group decision-making techniques (Lazakis, 2015, 2010). Several developments in those areas such as wireless sensors, prognostic and proactive strategies can be applicable in the shipping industry.

This paper will present a method for low cost incorporation of CBM in the operation of a ship. All the discussed reasons inhibiting the uptake are taken into account in the presented methodology. Section three of the paper will present a case study on the application of the proposed methodology. Finally, section four presents the concluding remarks of this paper.

2 METHODOLOGY

In order to overcome some of the obstacles in the uptake of CBM in ships a combination of stand-alone hardware and software had to be developed to provide a complete system for ship applications. The system had to satisfy data acquisition requirements for CBM and minimise investment costs and training. Also data confidentiality and security had to be ensured through the developed system. An overview of the methodology is presented in Figure 1.

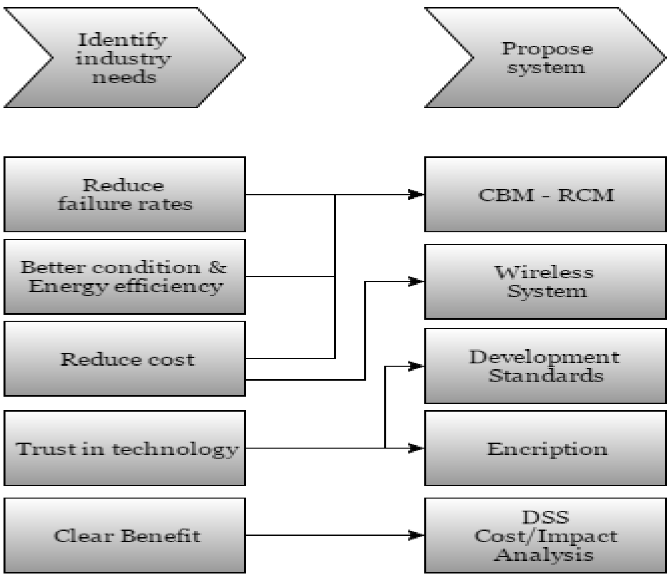

Figure 1. Methodology overview.

Based on the identified industry needs a new system had to be developed. This system would need to be based on CBM and also incorporate RCM in providing useful information to the user. Also to make the benefit of using this system clear to all stakeholders the processed data would need to be presented in a manner that associates identified faults in equipment with cost and impact on the overall operation of the business. The processed followed in order to develop this system is presented in the following section.

3 SYSTEM DEVELOPMENT

Figure 2 presents the application of the proposed methodology in developing a system that satisfies the identified industry needs. The following subsections will discuss the development of the system and are separated in the sensors and pre-processing phase, the wireless transmission phase and the post-processing and presentation phase. The section aims to cover both software and hardware development of the proposed system.

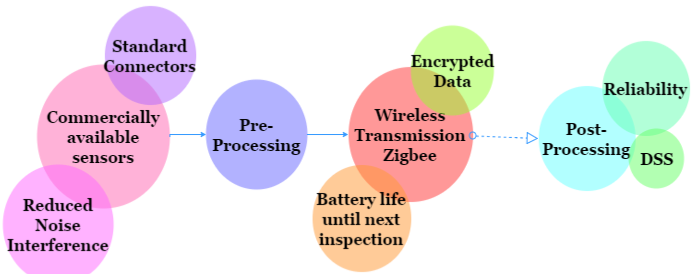

Figure 2. Development overview diagram.

3.1 *Hardware and pre-processing*

Standard CM sensors are utilised for this development covering temperature, vibration and pressure measurements for machinery. In that respect the development and installation cost is maintained low. All sensors are connected to an embedded processor through Bayonet Neill–Concelman (BNC) connectors which is a widely used method in the data acquisition domain. This allows for interfacing to a large variety of sensors available commercially. Also it reduces any noise affecting the signal. In that respect, sensors that are already installed on a ship can be connected to the wireless transmission system to facilitate continues monitoring.

The embedded system developed has firmware for pre-processing of two types of information. Value classed information and signal classed information. Information classed as value type includes temperature and pressure. Information classed as signal type includes vibration and some pressure signals. The pre-processing firmware for the first is a standard mean average and deviation exrtaction algorithm while the pre-processing firmware for the latter is based on Fast Fourier Transform (FFT) and Time Domain Analysis (TDA). The time domain analysis is based on peak-to-peak amplitude and variance feature extraction.

In both cases the firmware is developed to utilise minimum power resources so as to extend battery life of the wireless system. The firmware is developed to adjust the scrutiny of data accordingly when the system being monitored is identified as healthy or in potential onset of failure.

Table 1 presents a summary of the configuration settings available on the embedded system at installation time. Additionally, Table 2 presents the operating modes for each of the parameter settings. There exist three possible modes for the system at the moment. Sleep mode is when the system does nothing in order to save power. The length in seconds is derived from the required sampling rate for each measurement.

When the system is not sleeping it is recording either in Record mode for healthy system conditions or Failure Onset mode. The latter has an increased sampling period in order to identify if the recorded values are relevant to a particular failure being identified or just noise. Finally, if an internal error is identified and the device cannot perform as expected it goes into error mode. In that case it informs the system that it is malfunctioning and goes through a self-healing process. If the error is non-recoverable the device goes to sleep after producing a distress signal. In this eventuality, when the device is healed it goes in Attempt Join mode to reconnect to the mesh.

Table 1. Configuration settings.

Parameter	Setting
Measurement	Temperature, Pressure or Vibration
Type	Value or Signal
Measurement site	Text description of installation site
Range maximum	Highest acceptable reading
Range minimum	Lowest acceptable reading
Upper threshold	Highest for normal operation
Lower threshold	Lowest for normal operation
Encryption	Generated Encryption Key

Table 2. Default operation modes timing and data requirements.

Mode	Value Type		Signal Type	
	Sec	Bytes	Sec	Bytes
Sleep	58	0	1	0
Record	2	13	10	53
Failure Onset	20	130	100	530
Attempt Join	∞	1	∞	1
Error	∞	1	∞	1

3.2 *Wireless data transmission*

The embedded system contains a wireless communication chip programmed to use the Zigbee protocol for industrial wireless applications. The protocol is developed to operate in the presence of electromagnetic noise generated by operating machinery. Moreover to provide data transmission security especially when the ship is in port or near other wirelessly operated systems all messages sent through the Zigbee telecommunications chip are encrypted using a unique encryption key created at the time of configuration. This is key is particular to the installation and only applies to the system deployed on the specific ship.

On the other end, a system that received the messages using the same protocol is attached to a computer in the control room. In that respect, this becomes the data collection point and coordinator of the wireless mesh. Moreover, a set of commands can be transmitted from the coordinator in order to alter the configuration settings of any embedded system deployed. In that respect every sensor can be signalled to start recording more frequently, get out of sleeping mode or even change the parameters of each setting. Moreover other commands exist in order to test and fault find when the wireless system is not operating as expected. Finally, commands can be sent from the coordinator to add or remove devices from the wireless mesh.

Table 2. Wireless mesh commands.

Command	Description
Join	Tells any devices to join the mesh if they have the correct encryption key
Remove	Deletes a device from the mesh and forces it to sleep
Command	Protocol for custom command, used to allow expansion of the system
Mesh	Reports the status of the mesh
Channel	Custom change to the channel setting
Refresh	Removes and re-joins all devices (heal)
Reset	Resets the device to configuration parameters
Test	Forces a device to send a test message
Sleep	Forces a particular device to sleep
Wake	Forces a device to wake but does not alter the recording settings
Record	Forces a device to start recording
Failure Onset	Forces a device to record with Increased sampling rate

3.3 *Post-processing and data presentation*

After the data has been received in the central collection point, it must be post-processed so that useful information is presented to the user. As part of the INCASS (Inspection Capabilities for Enhanced Ship Safety) EU FP7 project, a Decision Support System (DSS) solution was developed that can be used onboard ships (INCASS, 2015b). The system requires minimal initial training as the advised actions are based on recommendations from survey, inspection, classification society guidelines and manufacturer recommendations already familiar to the engineers. The reliable user friendly graphical interface (GUI) developed in Java language provides relevant and on-time information regarding the current condition and maintenance planning. Also cost and impact analysis information is presented to the user through this interface.

The post processing stages start from the received raw data and using data mining and safety thresholds they are translated to reliability values. The next stage uses the reliability values calculated in order to predict the reliability of the system through the Machinery Reliability Assessment (MRA) developed for INCASS (INCASS, 2015a). Finally the outcome of the MRA is provided as input for the MRA-DSS software that produces the decision support guidance for the engineers onboard the vessel. Figure 3 presents this process.

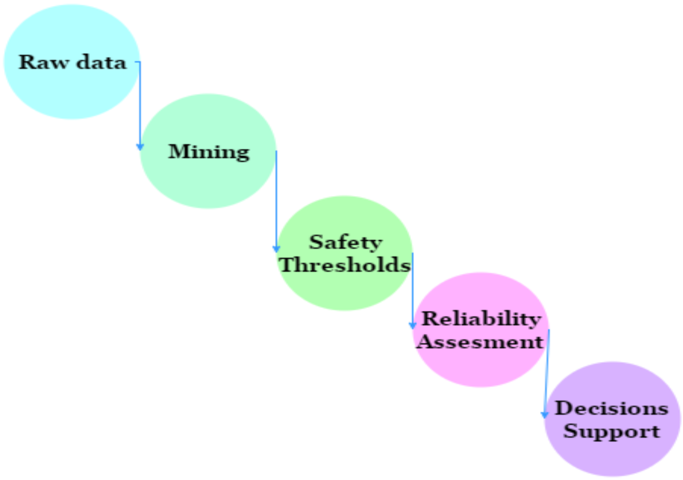

Figure 3. Post processing of data using MRA and MRA-DSS.

4 CASE STUDY

4.1 *Benchtop model development*

In order to validate the proposed methodology a benchtop model was developed. For this model a Beagle Bone Black (BBB) board was used and connected to a Zigbee development kit. Also BNC connectors were added to the analogue input ports of the BBB through an array of electronics used for signal conditioning. Also a cape was used for the connection of the BNC and required electronic components to the BBB. A pressure sensor was connected to the developed model in order to record values.

At configuration the system was setup to record Value Type and Pressure. A unique encryption key was generated by the coordinator at setup through a random generator. This key was then introduced to the end device through the configuration interface.

Figure 4 presents the method of connection between the components of the system. For clarity the wires, resistors and capacitors used are omitted from this image. This setup is used for the end device that is connected to the sensor. The coordinator is only comprised of the wireless development kit and the antenna.

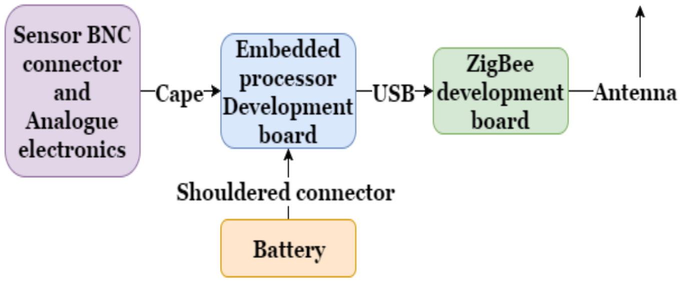

Figure 4. Benchtop model components without resistors capacitors and wires.

4.2 *Preliminary test case, CBM data and DSS*

For the initial test case of the developed benchtop model a pressure sensor was connected to the system. Data recorded from air pressure through the sensor is presented in Figure 5. The sensor was excited by increasing pressure using an air pump. The recordings were continuous over a 24 hour period.

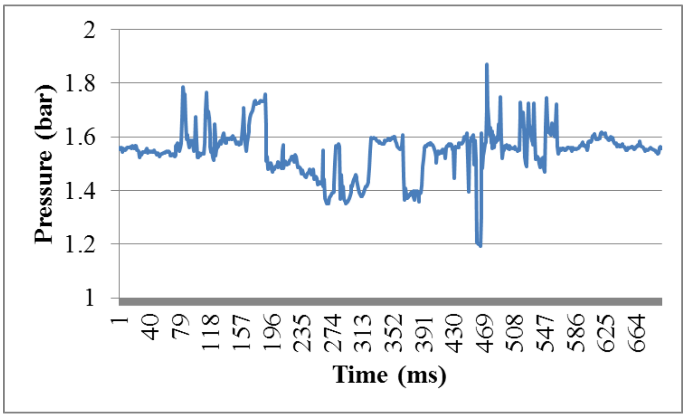

Figure 5. Raw data collected from the sensor without preprocessing.

During the same recording session all the data that was pre-processed through the algorithm was transmitted to the central collection point and the raw data stored locally on the device. In that respect, two sets of data were collected. The raw-data presented in Figure 5 and the pre-processed data points presented in Figure 6.

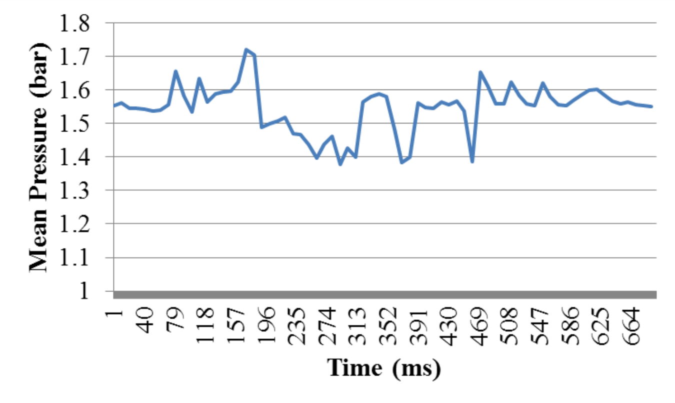

Figure 6. Pre-processed mean pressure data received.

As demonstrated in Figure 7 the two data sets are very well correlated. In that respect the pre-processing algorithm does not alter the information conveyed in regards to the condition of the monitored system.

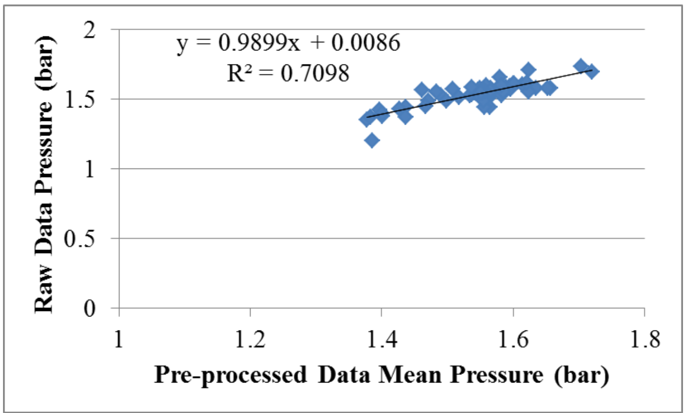

Figure 7. Data sets correlation.

Finally, the pre-processed set was wirelessly transmitted to the coordinator and passed on to the post-processing software. Using the transmitted information a post-processed set of data was reverse engineered to populate the full time series of the 24 hour period. These were generated per transmitted data using the mean average and deviation information.

Then both the raw data and post-processed data sets were evaluated through the MRA and DSS software. The result was the reliability of the measured system. For this case study the values were assigned to an air pipe of the main engine for the MRA tool to be able to process and assess the data. Also the thresholds for upper and lower permitted values were assigned to 2 and 1 bar respectively. Figure 8 presents the predicted condition based on the raw set of data that was extracted from the device directly.

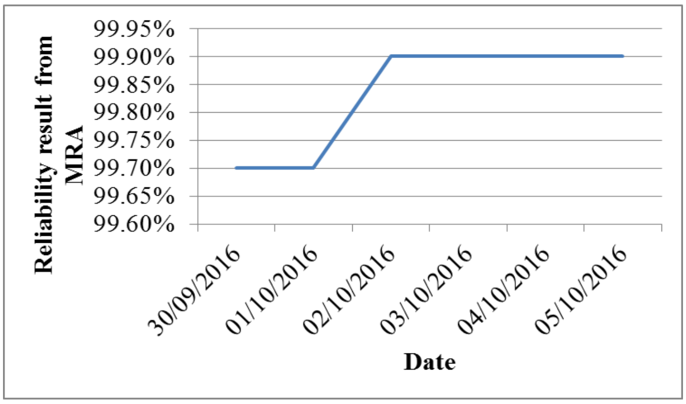

Figure 8. Predicted condition based on first set of data.

On the other hand the pre-processed set was transmitted and post-processed before passed as input to the MRA and DSS software after the end of the recording session. Figure 9 presents the predicted condition of the same system based on the transmitted set of data. As demonstrated from the comparison of Figure 8 and Figure 9 the difference between the predicted reliabilities are not statistically significant.

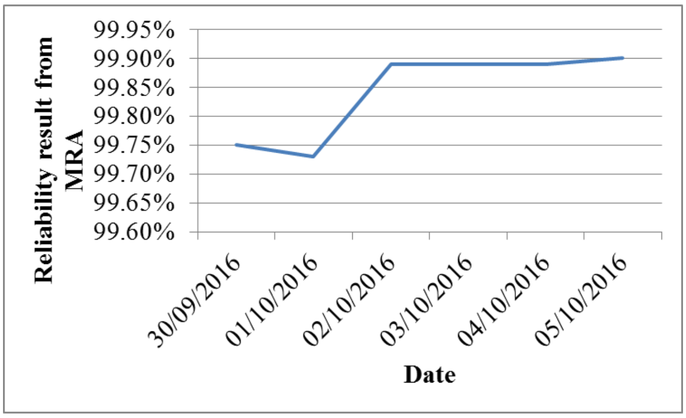

Figure 9. Predicted condition based on second set of data.

Finally, the results of the MRA/DSS tool for both the data sets were evaluated for correlation as presented in Figure 10.

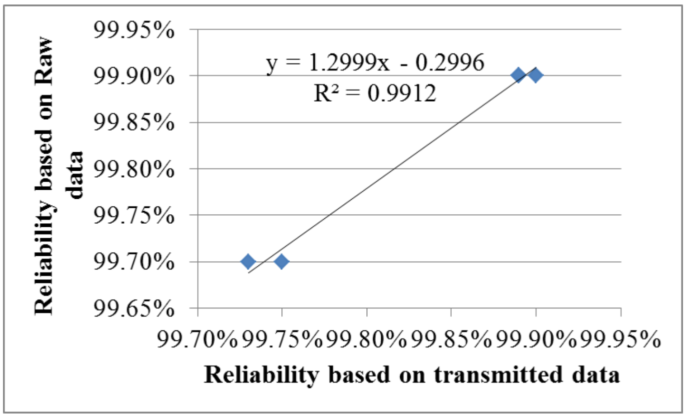

Figure 10. Correlation of the two predicted reliability result sets

This method of comparison validates that the two sets of data provide the same result in terms of condition monitoring and predictive maintenance. Also in that respect the same actions were suggested by the DSS in both the cases.

5 CONCLUSION

The combination of the developed hardware and software give a complete solution for CBM on ships. This solution addresses some of the most important concerns of the industry. Those concerns are the installation cost, the security of data and the requirements in training of staff in order to use CBM technologies. Through the reduced cost of the hardware and software as well as minimal installation cost requirements the capital investment is maintained low. Also through the DSS system the interpretation of CBM data is directly related to maintenance actions and the direct benefit of CBM becomes easily identifiable. Overall the proposed approach can stimulate higher industry uptake. However, more work is necessary to validate the proposed method in the shipping environment. Acknowledgements

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