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IMPLEMENTATION OF A REMOTE MONITORING SYSTEM FOR CONDITION-BASED MAINTENANCE USING WIRELESS SENSOR NETWORK: CASE STUDY

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ABSTRACT

Increasing number of interconnected embedded "SMART" devices pervade our environments. Their use in various scenarios including smart-city, building-automation, industrial control, energy grids etc. have dramatically improved the overall performance. Use of IoT (sensors, actuators etc) and wireless sensor networks WSN) can help to sense and act based on real-time monitoring of industrial equipment. Our proposed architecture explores the advantages of embedding smart sensors on industrial equipment and collect data for monitoring and better maintenance. This real-time monitoring will enable predictive analysis for the health status of industrial equipment. To the best of our knowledge, this article is the first investigation of employing intelligent network sensors in case of remote maintenance applications that couple information technology solutions with condition-based maintenance. Tests are carried to prove the validity of our proposed system by using Contiki based Cooja emulator. Although the technique developed in this work is tuned toward this application, it could be used in other applications as well which deals with condition-based maintenance.

Keywords: *Condition Based Maintenance, Wireless Sensor Network, Decision Support Systems, Asset Management, Contiki-Cooja.*

1. INTRODUCTION

In the past decades, the industrial sectors in Morocco have been witnessed a booming success in redefining its place in the world. Industrial sectors like automotive, electronics and aeronautics along with its subcontractors have not only evolved as an important part of Morocco but also helps the country to thrive. Quite recently the world is engulfed by the "smart" devices. The industries too can be benefitted from these new technologies as they are quite promising. In this context, our article ventures an interesting idea of employing sensors on industrial equipment for condition-based monitoring which we can achieve with the help of wireless sensor networking (WSN). This coupling of different technologies has been proved successful in different applications like the environment[1], agriculture[2], applications in the medical field[3], and automation[4]. Moreover, they do not only help to monitor but also to predict and detect critical incidents before it can turn into disastrous.

More recently manufacturers start employing WSN based application in their productions for better monitoring and real-time data collections. In this article, they present overview of state-of-art in real-time sensing for industrial applications [5] along with WSN applications for industry operations [6][7]. However, the proper adoption of WSN applications for industrial settings requires extensive experiments as types of communication protocols and choice of motes (sensors)

depends on various scenarios. Moreover, simulations based experiments of these sensors prior to deployment

help to determine their performance and thus save money for the industry.

Our article fills the gap in existing literature and proposes a simulation-based approach that helps

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the industry to check the viability of any WSN applications before employing them over industrial setting; which saves operation costs and improve the real-time monitoring of condition-based maintenance (CBM).

In this regard, the main research problem of this article is to explore methods to find effective and low-cost remote monitoring systems based on smart sensors for condition-based maintenance of large industrial machines. This real-time sensing enables real-time actions and decisions for maintenance.

Our application will be performed in a thermal power station in Morocco. The remainder of this paper is structured as follows: The first section present condition based maintenance management within the context of the wireless sensor network. Section 2 presents the algorithm of condition-based maintenance using wireless sensor network. Section 3 illustrates our proposed approach. Finally, the conclusions and future research constitute section 4.

2. CONDITION BASED MAINTENANCE WITHIN A WSN CONTEXT

2.1 Condition based maintenance and its operations management

- **Condition-based maintenance**

Condition monitoring systems are used to monitor the condition of equipment. This policy can significantly reduce the number of unnecessary maintenance since it is based on maintenance actions carried out only if needed and at the right time. In the literature, many articles review [8] and treat the problematic of condition-based maintenance. The reference [9] describes how CBM can be used to optimize maintenance strategies and increase the feasibility and practicality of a condition based maintenance system and [10] develop a framework for condition-based maintenance for a proactive decision making. Some works underline the link between E-maintenance and CBM as an evidence of the fact that advanced information technology solutions are being adopted in manufacturing processes. Furthermore, [11] presents a framework for effective management of condition-based maintenance programs in the context of the industrial development of E-Maintenance strategies. However, there is not much research has been done that couple condition-based maintenance with the wireless sensor network.

- **Functionality of condition-based maintenance**

The functionality of a condition-based monitoring system is presented by the ISO 13374MIMOSA OSA-CBM, it is an organization and data standard information involved in the development of the standards for CBM, it defines the data transfers and interfaces of an automated condition monitoring system. This standard divides the equipment condition assessment to 6 blocks of functionality: data acquisition (DA), data manipulation (DM), state detection (SD), health assessment (HA), prognostics assessment[12].

- **Procedure of condition-based maintenance**

In this work, we will try to develop an approach for the integration of intelligent networks sensors in case of remote monitoring applications in condition-based maintenance. The following steps will take into consideration the organizational and technical aspects according to the international standard ISO 13372. Furthermore, it provides guidance for condition monitoring and diagnostics of machines which are shown in [13]. It sets out general procedures to be considered when setting up a condition monitoring program for all machines. The general steps for applying the condition maintenance method are summarized in figure 1, but in the phase of data collection and analysis, the integration of WSN in the context of CBM is not explained. This is why in the next sect (paragraph 3) we will explain the different steps needed for this implementation.

2.2 Technical requirements for condition-based maintenance using intelligent network sensors.

In manufacturing, new technologies and in particular the use of digital technology has enabled innovative features within intelligent sensors (e.g., measuring a multitude of parameters frequently and collecting run-time data for analysis and monitoring). Moreover, the use of digital technology also helps to integrate self-healing techniques like correction of measurement errors, self-adjustment, self-diagnosis, dynamic reconfiguration and finding efficient and low-cost network communication. Above mentioned five features play, directly or indirectly, a role in the

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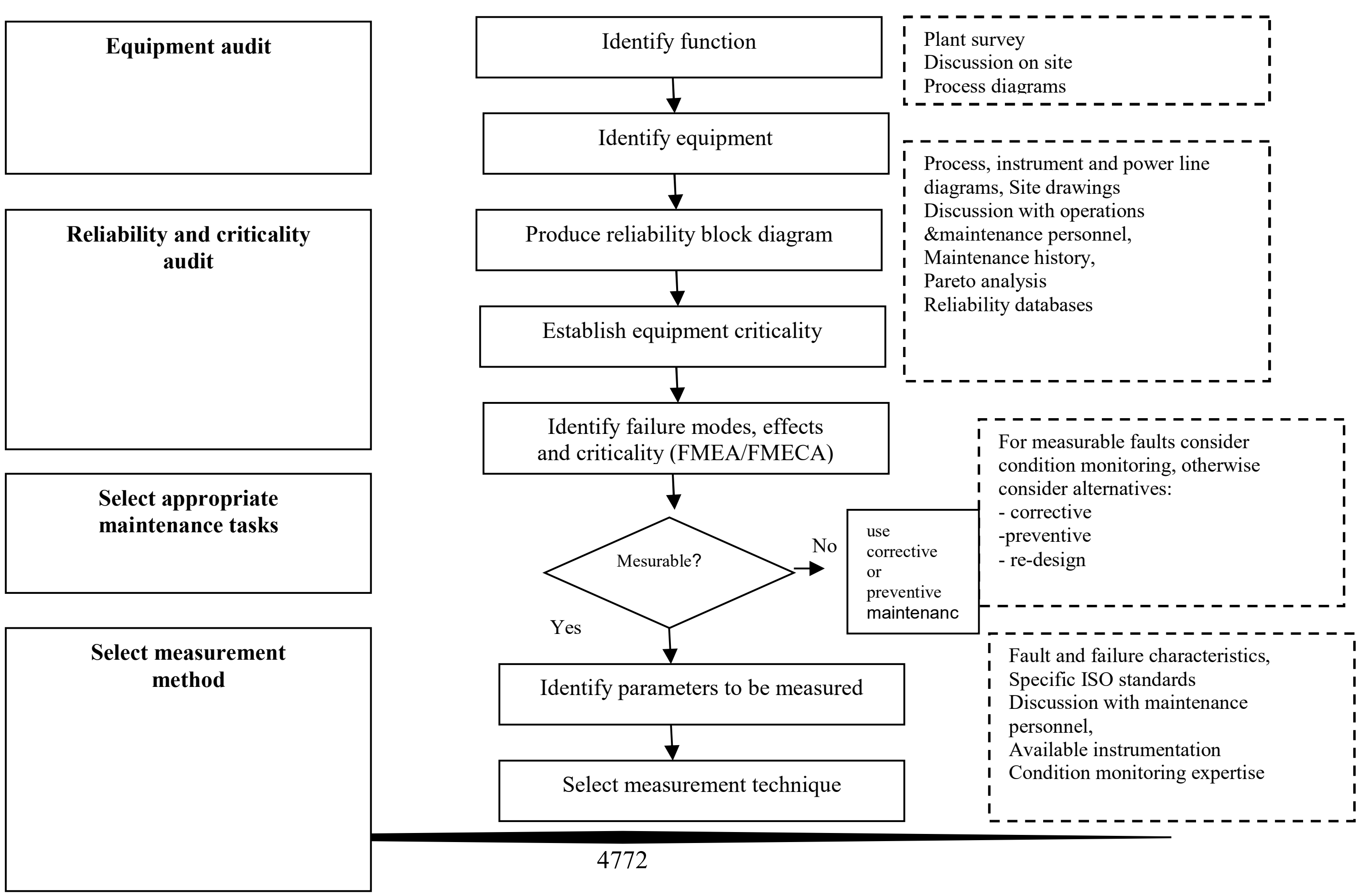
generic functions of an intelligent sensor. In order to define all the constructive functions of our remote monitoring system within condition-based. We have developed a Functional Analysis System Technique (FAST) diagram, which will clarify the technical functions choices for our system of Telemonitoring (as shown in figure2).

3. STRUCTURED STEPS OF DATA COLLECTION AND ANALYSIS USING WSN FOR APPLYING CBM

In this paragraph, we will use conceptual steps during the phase of data collection and analysis using the technology of intelligent network sensors. This helps maintenance staff to deploy an effective WSN application for condition-based maintenance.

We describe prior steps to be followed for employing WSN application for condition-based maintenance in an industrial setting. It is indeed crucial to determine the correct choice of the organization of the network, number, and typology of sensors, network topology, geographical distribution for better performance and monitoring. To achieve this we follow below-described steps:



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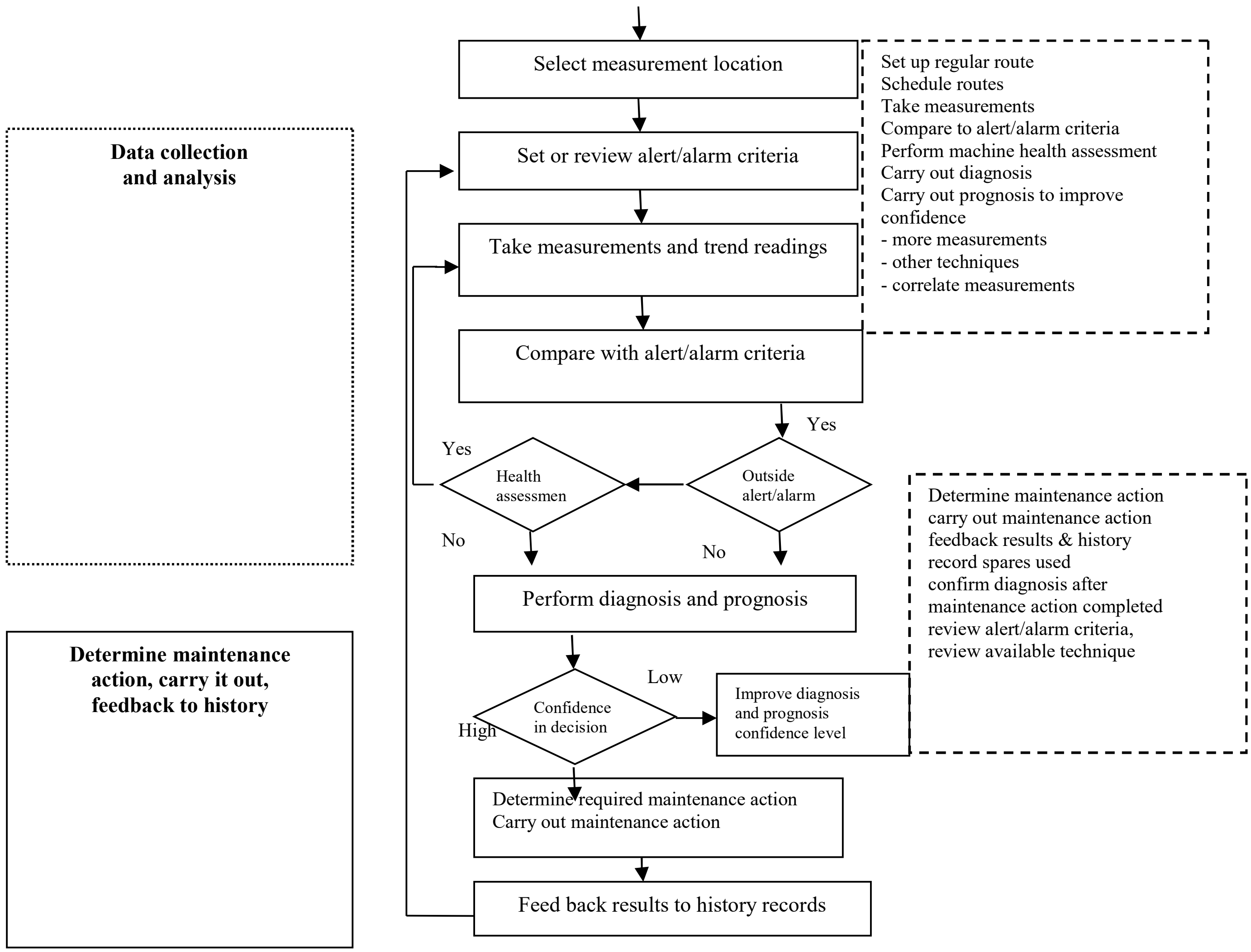

Figure 1: Procedure to implement Condition Based Maintenance

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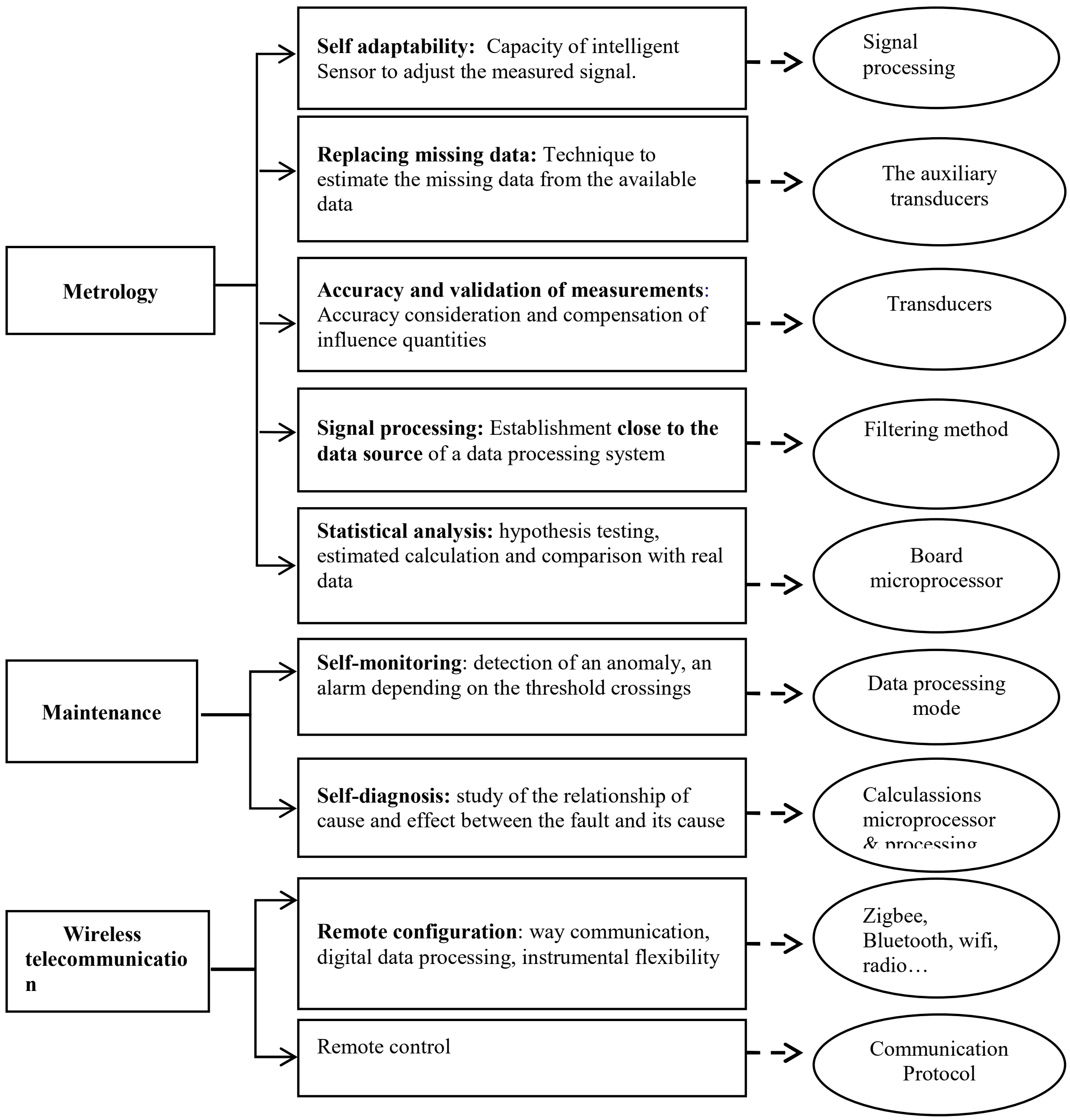

Figure 2:FAST Diagram of an Intelligent Sensor Network for Remote Monitoring

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3.1 Typology of sensors to be installed:

Choose the types of sensors to be installed on the machines, i.e. identify the physical quantities and the significant parameters with the sensors that correspond to their measurements.
A wireless sensor node is a small electronic device capable of measuring an environmental physical value such as (e.g., temperature, sound, vibration, pressure, motion) and communicating it to a control center via a base station. It is composed of four basic units [18] as shown in figure3:

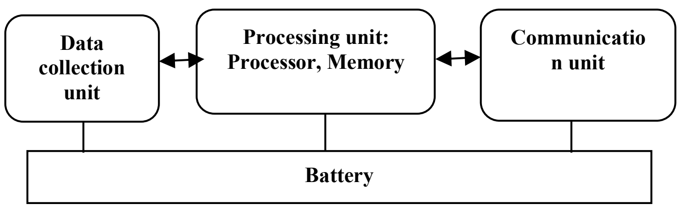

*Figure 3: **Architecture of a sensor node***

Overall functionalities of the sensors are as follows:

1. They will sense data and transmit the data to the control node, which we can call as a super-node.
2. Supernode (which is also a sensor) will receive all the data from other sensors and transmit them to the control manager.
3. In case of an unlikely event of an emergency where the control manager fails to take the decision, the super node can shut down the whole operation. This automation part is also simulated in our experience which we have discussed in next section.

3.2 Topology of the sensors:

The topology architectures used in WSNs include star, mesh and cluster tree topologies, as shown in figure4. The right topology depends on the amount and frequency of data to be transmitted, transmission distance, battery life requirements and mobility of the sensor node. A star topology is a single-hop system in which a particular node, called coordinator, manages communications and all remaining nodes communicate only with it. It is a sort of master-slave structure where the coordinator acts also as a bridge towards other networks. Moreover, star topology is a power-efficient solution that ensures a long network life even if a node collapses, but it can only handle a small number of nodes. This is not a real limit since in many cases communications among coordinators use wired links. Mesh topologies are multi-hopping systems in which all nodes are identical and communicate with each other so that a coordinator or base station is not strictly needed. The multi-hop system allows for a much longer range than a star topology at the cost of higher power consumptions rate and higher latency. In fact, nodes have a high duty cycle since they need to ‘‘listen to’’ messages and network changes and latency is related to the number of ‘‘hops’’ between the source and the sink. The aim of star–mesh hybrid architecture (also known as cluster tree) is to take advantage of the low power and simplicity of the star topology, as well as the extended range and self-healing nature of a mesh one. Nodes are organized in a star topology around routers or repeaters, which, in turn, organize themselves in a mesh network.

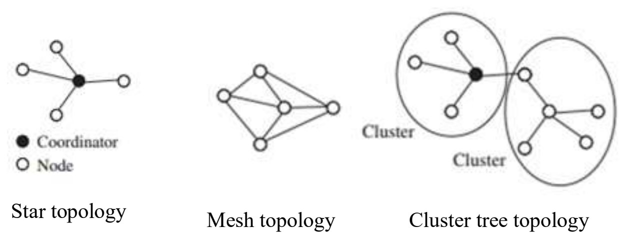

Figure 4: Topology of sensors node

3.3 Positioning of the sensors

Measurement locations should be chosen to give the best possibility of fault detection. Measurement points should be identified uniquely. Indeed, some sensors give erroneous values due to incorrect location or non-compliance with the manufacturer's instructions. As an indication, the transmission of data may be altered due to the presence of obstacles in the vicinity of the sensor. On the other hand, the presence of a source of heat or dust in the ambient air can distort the measurements

3.4 Protocol of communication

choice of protocol of communication: The analysis of the type of standard was based on a comparison of the main characteristics of these, namely the frequency of transmission, throughput, distances covered, type of network architecture, energy consumption, targeted applications, complexity, the use on a large scale or not, the possibility of using it in industrial environment.

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4. ALGORITHM OF CONDITION BASED MAINTENANCE USING WSN CONCEPTS: APPLICATION IN INDUSTRIAL COMPANY

4.1 Case study of the proposed CBM integrating WSN

A Turbine, shown in figure5, was selected for a case study. It is a rotary device intended to use the kinetic energy of a liquid fluid such as water or gas (steam, air, combustion gas), to rotate a shaft supporting the vanes of the turbine equipped. The turbine is equipped with 19 simple wheels and one double, the Steam flow at admission is 286000 kg/h, its exhaust steam flow is 192000 kg/h and the rotation speed is 3000 tours/min.

Due to working continuously in a high-pressure environment, the turbine frequently breaks down from two critical mechanical failure modes: vibration of the thrust bearing damage (shown in figure6) and the high temperature of the metal thrust bearing. We take this problem as our motivation to develop our approach to this problem most common faults in industrial machines. They are causing unplanned downtime on essential production equipment because changing the vibration of a machine is often the first physical manifestation of an anomaly

Figure 5: Turbo-alternate chosen for the case study, 75MW

As we cited below to take a good measure, is necessary to choose the location and the direction on which the measurement is taken. In practice, three modes of measurement can be distinguished to measure the vibration of the thrust bearing figure7: absolute vibration of bearings; relative shaft vibration and absolute vibrations of the shaft that is rarely used. In our case, we choose the absolute vibration. Absolute vibration is measured by seismic sensors called accelerometer or velocimeter, ideally placed on the bearings of the machine. Although the vibrations are not generated by the bearings, they are the connection points between the rotor, which generates the vibrations, and the rest of the machine.

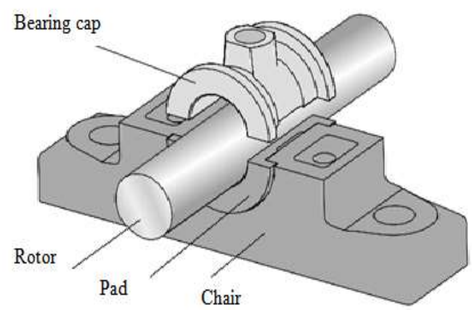

Figure 6: Thrust bearing

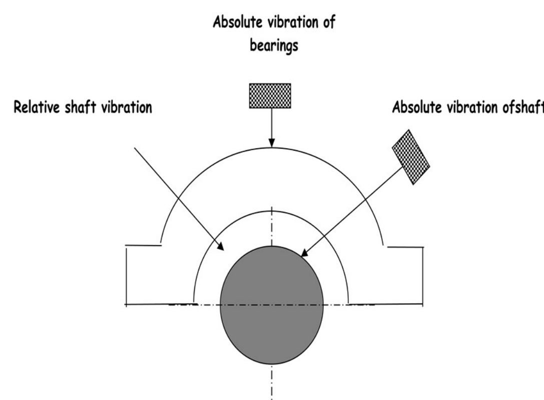

Figure 7: vibration position measure

For the second breakdown, Temperature of the metal thrust bearing. As we know the purpose of the thrust is to fix the relative position of the rotor relative to the body of the turbine. The bodies are constructed in such a way that axial thrusts on the rotor, due to the flow of steam through its bodies practically cancel each other out; the forces on the stop are therefore low. When abnormal forces are applied to the stop during periods that are too long, the runners of the stop wear out. The wear of these pads, when it becomes dangerous, causes the triggering of the turbine figure8.

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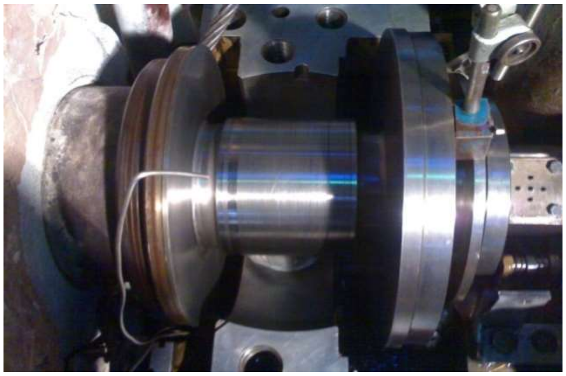

Figure 8: Thrust bearing patin

In this article, we propose a condition-based continuous real-time monitoring by employing intelligent smart sensors. We use WSN application in order to make smart sensors enable to monitor the failures of the turbine and transmit data to the maintenance staff on a real-time basis. The main motivation for using WSN application is its flexibility and low-cost and easy implementation of wired communications. WSN application offers a plethora of features that are customizable based on end user requirement. In general monitoring of industrial equipment does not have real-time support. The classical approach for monitoring consists of data acquiring, later the data is saved to a central hub for analysis. Thus making it unsuitable for run-time monitoring or critical real-time decision making. Especially these historical data cannot be of much use for determining "health" of the equipment and data can't share with the providers' service that is responsible for the maintenance interventions. However, WSN applications, on the other hand, can not only monitor the industrial equipment in real-time but also transmit the data to the maintenance staff for run-time analysis by a warning alarm whenever something wrong is detected. Moreover, these features facilitate maintenance staff to take immediate measure in case of an unlikely event of machine failure.

Apart from being easily available and user-friendly, the deployment of smart sensors enables the maintenance staff to add another layer of security to the industrial machines. The central node is programmed to shut down the whole system in case of emergency, like upon receiving threshold values from any of the other sensors, the central-node will shut down the machine. Thus saving it from causing a fatal issue that causes downtime or damage to the system. In other function data can transmit to the subcontracting service that responsible for the analysis of the machine's behavior and failure in real time to permit them to do interventions if necessary.

In our proposed architecture of remote monitoring and based on the failure analysis of our equipment, we have shown the simulation of four sensors: temperatures and vibration parameters to determine the conditions of environmental changes and updates those measured values that detects abnormal or suboptimal machine behavior in order to prevent equipment from further deterioration.

4.2 Proposed Architecture

Our proposed architecture of wireless sensors network consists of four sensors and a supernode; the deployed sensors will follow the de-facto IEEE 802.15.4 framework and use 6LoWPAN as the communication protocol with the supernode/central node. However, the super-node will transmit data to the central monitoring through the edge router. From the central database, data can be accessed to mobiles/laptops or other end-user applications which operated by the control manager and technicians staff using 4G LTE network. For our simulation purpose, we have used Tmote sky sensors [14], which is one of the main actors in the wireless sensor network system. The monitoring system is continuous and capable of closing down the operation in the unlikely event of receiving alarming values from the sensors.

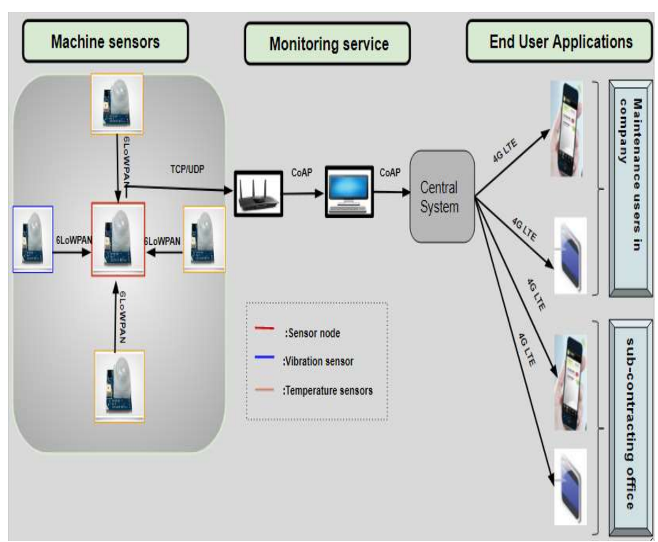

Figure 9: Design of the proposed architecture

4.3 Evaluation Platform of simulation:

Adopting WSN applications into an industrial environment requires exhaustive simulation phase to ensure proper functioning of all devices. Indeed, for large networks, the number of sensors can reach several thousand and therefore a relatively significant financial cost, hence, necessary to minimize the errors of design possible by conducting a validation phase. In this context, we have set up an experimental platform that aims to test, validate and simulate the operation of a wireless sensor network. The main function is to check the behavior of the developed sensors and the communication protocols even before deploying them in a real situation. To simulate our wireless sensors network we will use the simulator Contiki OS application [15].

- *Contiki Operating System:*

Contiki is a lightweight open source software written in the C programming language for wireless sensors networks[16]. It follows a modular architecture. It is a network simulator that allows developers to run and test their applications on fully emulated hardware devices and tests their code before running it on the real target hardware. Moreover, it supports energy efficient low-power modes for the supported microcontroller and provides different routines to calculate energy consumption on a run-time basis.

- *Cooja Network Simulator:*

Cooja is a platform that can be used to emulate networks of resource-constrained devices, communicating with realistic protocols. One important feature of Contiki project is the Cooja simulator. It provides the unique opportunity to test Contiki applications, [17]explain the steps to use Cooja, it has been developed in JAVA language. It allows simulation of a single wireless node or a whole network on a standard device without the real physical existence of those devices. The unique GUI features allow end users to simulate their desired scenarios with precise accuracy. Cooja is used to simulate platform and testing applications in different fields such as health[18], agriculture[19] and greenhouse management[20]. Furthermore, in the optimization of power consumption[21]. For our simulation purpose, we will use Cooja as the simulation platform that allows us to test our code and systems before running it on the real hardware.

4.4 Simulation experimental Setup in Cooja and discussion of results

- **Sensors and its topology**

For our simulation purpose, we have considered 5sensors. Out of which one node will act as a central hub. The overall node setup resembles the conventional “Star” topology by forming a tree where the central node is root and other nodes are the leaf (child).

- The reasons behind choosing star topology are as follows: In a local area networking, star topology provides the most reliable communications among devices. In our set up we need continuous and infallible communications for real-time monitoring.
- The central “hub” (sensor) will transmit the receiving data from different nodes to the monitoring centre.
- The central “hub” will have intelligence property. Like, upon receiving alarm messages from any of the deployed nodes it can shut down the system. This implies another level of safety measures for the large and costly systems.
- Star topology is easy to deploy and easy to maintain. As an example, it’s easy to replace or add any nodes to the network without affecting the whole network.
- Ease of deployment and maintenance has advantages for installing large systems which incur the cost.
- The “Centralized” approach provides by star topology helps to troubleshoot issues which have a direct impact on system performance and monitoring.

- **Sensors and Communication protocol**

Choosing the communication protocol among nodes is crucial as it makes reliable and uninterrupted data transmission to the central node. Although we have many communication protocols available for sensors, but we focus only on ZigBee and 6LoWPAN due to their adaptability for this particular purpose. Furthermore, we keep Bluetooth communication protocol out of our scope, due to its nature to be more suitable for personalized devices. ZigBee has a large user base like Bluetooth. Moreover, ZigBee is more suitable for complex Industrial systems [22]. The main advantages of using ZigBee that offers low-power operation, high security, robustness, high scalability in M2M and ZigBee PRO and ZigBee Remote Control (RF4CE) are based on the IEEE802.15.4 protocol.

On the other hand, newly emerged key IP protocol is 6LoWPAN (IPv6 Low-power wireless Personal Area Network). 6LoWPAN has been proved as the

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better candidate for IoT communication over other protocols due to its adaptability[23]. The advantages are:

- 6LowPAN is a network protocol that defines encapsulation and header compression mechanisms.
- The standard has freedom of frequency band and physical layer and can also be used across multiple communications platforms.
- It provides a mean of the cost-effective way to communicate with devices/sensors in a network via a low-power wireless network.

For our simulation purpose, we have used 6LoWPAN due to its flexible adoption into industrial IoT. Interoperability is one of the leading reasons for favoring 6LoWPAN over ZigBee. Unlike ZigBee, 6LoWPAN offers interoperability with other wireless 802.15.4 devices as well as with devices on any other IP network link. This feature helps to integrate with already existing systems with low-cost. Moreover, IP routing over 6LoWPAN links does not necessarily require additional header information at the 6LoWPAN layer. This ease packet overhead and allows more room for the payload data. Also, the typical code size for a full-featured stack is 90KB for ZigBee and only 30KB for 6LoWPAN.

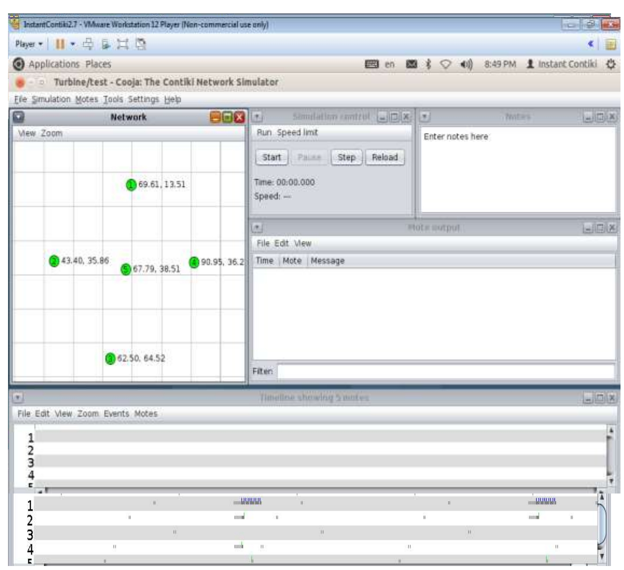
For our simulation, we use Tmote sky as our simulation node for the experiment. Apart from being low-cost and energy efficient, it is equipped with 16-bits 8~kHz MCU, 10~KB of RAM, and 48~KB of nonvolatile memory. Broadcast communication, for the purpose of data transfer to the central node, is carried out over the IEEE 802.15.4 MAC layer protocol, and using 6LoWPAN as an adaptation layer (using Contiki modules). This configuration is very popular in IoT settings. The IEEE 802.15.4 protocol provides a maximum data rate of 250Kbps, a maximum coverage of 75m, and a frame size of 127B. Simulations are carried out with the COOJA simulator using the feature configuration shown in Table 1.

TABLE I : A Features Configuration Used In Simulation

Configurations	*Values*
Communication range	55 m
Interference range	60 m
Type of sensor node	skyMote
Number of mobile sensor	4 + one sensor node
Number of linked sensors	4
MAC layer	CSMA+ContikiMAC
Radio interference	CC240 2.4 GHZ IEEE

- **Results of simulation**

The results of our simulation are quite promising and they are shown in these different figures. In our case study, we use a single router and 5 sensors out of which 3 sensors temperature sensors (will monitor the temperature continuously and transmit the data to the central node), one sensor for monitoring vibration sensor and one sensor node as a central node to collect all the data from other 4 nodes. The overall architecture is depicted in the figure10.



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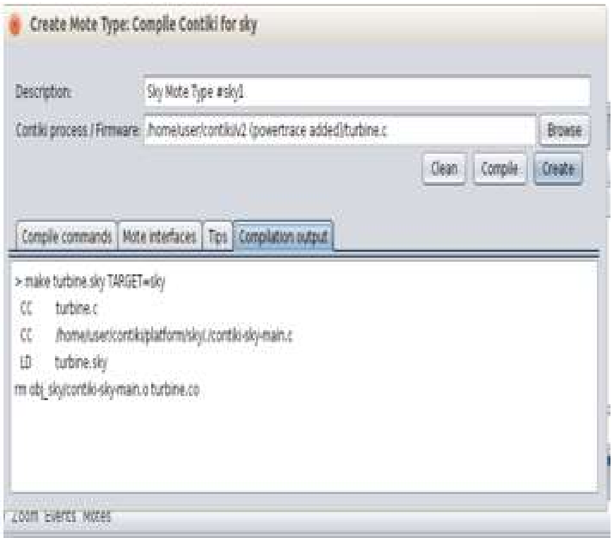

Figure 10: Visionary sensor on Cooja

The compilation of the program shows that is run successfully figure11.

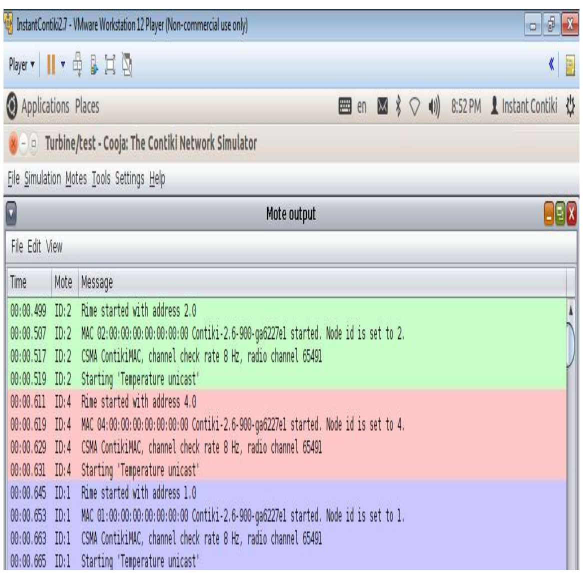

Figure 11: Graphical Interface Of Our Network On The Simulator Cooja

We ran our simulation on Cooja platform. As shown in figure 12. These nodes will send data to a central node. Below figures are taken from the simulation which shows data transmissions to the central node from other nodes. Furthermore, the simulation also yields the alarm point and the message has been sent to the central node. Upon reaching the critical value the central node shut down the whole system. Through this step, we have achieved the intelligent automation for this WSN application. This automation works as an extra layer of safety measure that can prevent system failures.

Figure 12: Messages Send By The Sensors (Normal Values, Alarmed Values And Values Shutting Down The Machine)

- Evaluation

This section evaluates our application through simulations. In order to validate the performance of our approach we evaluated our design on realistic networks using the Instant Contiki environment, and in particular, the Cooja simulator. We used Cooja to investigate the robustness of our system in a scenario where nodes

(sensors) will collect data on a real-time basis and transmit to the central node. The real-time data is transmitted to the central monitoring system for run-time analysis and the same is available for the intended people via web applications. These first results obtained by simulation using the Cooja simulator are satisfactory. As a second line of security measure, we have designed automation for our system. In case the control person makes any mistakes or they forget to take immediate measures in emergency situations then the central node can take the emergency decisions and stop the

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machine. This feature is also tested through simulation.

5. CONCLUSION

This paper will consolidate the know-how for manufacturers and service providers in the implementation of an intelligent sensor system in condition-based maintenance for real-time monitoring of industrial equipment. This article emphasis on the practical engineering solutions, principally which sensors devices are used, what they are used for, identification of sensor node configurations and network topologies. Which will generate a major contribution for Moroccan companies. The thing that has been proved by this survey [24], where more than 90% of industrial people believe that there is a real need for a remote monitoring system and that the implementation of this last has an impact on sustainable development.

As a future work, it is planned to venture towards a complete implementation of this architecture which will consist of not only embedding sensors on industrial equipment but also a web application that can empower maintenance staff or other authorized people to monitor the data from anywhere. Moreover, a study energy consumption of different sensors with different protocols is planned. This will help different industries to choose their required sensor and communication protocol for customized operations.

REFERENCES:

[1] Q. Chi, H. Yan, C. Zhang, Z. Pang, and L. Da Xu, “A reconfigurable smart sensor interface for industrial WSN in IoT environment,” IEEE Trans. Ind. Informatics, vol. 10, no. 2, pp. 1417–1425, 2014.

[2] Z. Liqiang, Y. Shouyi, L. Leibo, Z. Zhen, and W. Shaojun., “A Crop Monitoring System Based on Wireless Sensor Network,” Procedia Environ. Sci., vol. 11, pp. 558–565, 2011.

[3] E. Jovanov, A. O. Lords, D. Raskovic, P. G. Cox, R. Adhami, and F. Andrasik, “Stress monitoring using a distributed wireless intelligent sensor system.,” IEEE Eng. Med. Biol. Mag., vol. 22, no. 3, pp. 49–55, 2003.

[4] A. Van Den Bossche, E. Campo, N. Vigouroux, and F. Vella, “Réseau de capteurs sans fil distribués pour le monitoring des activités de vie au sein d ’ une maison intelligente,” vol. 3, no. 1, pp. 3–7.

[5] A. Flammini, P. Ferrari, D. Marioli, E. Sisinni, and A. Taroni, “Wired and wireless sensor networks for industrial applications,” Microelectronics J., vol. 40, no. 9, pp. 1322–1336, 2009.

[6] M. R. Akhondi, A. Talevski, S. Carlsen, and S. Petersen, “Applications of Wireless Sensor Networks in the Oil, Gas and Resources Industries,” Adv. Inf. Netw. Appl. (AINA), 2010 24th IEEE Int. Conf., pp. 941–948, 2010.

[7] M. C. Garcia, M. A. Sanz-Bobi, and J. del Pico, “SIMAP: Intelligent System for Predictive Maintenance. Application to the health condition monitoring of a windturbine gearbox,” Comput. Ind., vol. 57, no. 6, pp. 552–568, 2006.

[8] J.-H. Shin and H.-B. Jun, “On condition based maintenance policy,” J. Comput. Des. Eng., vol. 2, no. 2, pp. 119–127, 2015.

[9] A. Prajapati, J. Bechtel, and S. Ganesan, “Condition based maintenance: a survey,” J. Qual. Maint. Eng., vol. 18, no. 4, pp. 384–400, 2012.

[10] A. Bousdekis, B. Magoutas, D. Apostolou, and G. Mentzas, “A proactive decision making framework for condition-based maintenance,” Ind. Manag. Data Syst., vol. 115, no. 7, pp. 1225–1250, 2015.

[11] A. J. Guillén, A. Crespo, J. F. Gómez, and M. D. Sanz, “A framework for effective management of condition based maintenance programs in the context of industrial development of E-Maintenance strategies,” Comput. Ind., vol. 82, pp. 170–185, 2016.

[12] T. Alexander, L. Binh, I. Conference, and B. P. Management, “This is the author version of article published as :,” pp. 206–219, 2005.

[13] ISO 17359:2002, “Condition monitoring and diagnostics of machines - General guidelines,” Int. Organ. Stand., vol. 2002, no. 50, 2002.

[14] Moteiv Corporation, “Moteiv: tmote sky low power wireless sensor module,” Prod. Data Sheet, pp. 1–28, 2006.

[15] M. Jevtić, N. Zogović, and G. Dimić,

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

"Evaluation of Wireless Sensor Network Simulators," Proc. 17th Telecommun. Forum TELFOR 2009 Belgrade Serbia, pp. 1303–1306, 2009.

[16] A.~Dunkels, B.~Gronvall, and T.~Voigt, "Contiki -- A Lightweight and Flexible Operating System for Tiny Networked Sensors," LCN '04 Proc. 29th Annu. {IEEE} Int. Conf. Local Comput. Networks, pp. 455–462, 2004.

[17] A. Sehgal, "Using the Contiki Cooja Simulator," Comput. Sci. Jacobs Univ. Bremen Campus Ring, vol. 1, p. 28759, 2013.

[18] P. Kugler, P. Nordhus, and B. Eskofier, "Shimmer, Cooja and Contiki: A new toolset for the simulation of on-node signal processing algorithms," 2013 IEEE Int. Conf. Body Sens. Networks, BSN 2013, 2013.

[19] B. Khelifa, D. Amel, B. Amel, C. Mohamed, and B. Tarek, "Smart irrigation using internet of things," 2015 4th Int. Conf. Futur. Gener. Commun. Technol. FGCT 2015, no. Fgct, pp. 91–96, 2015.

[20] T. Coimbatore, "RPL Optimization for Precise Green House Management using Wireless Sensor Network," Icgccee, pp. 1–6, 2014.

[21] A. Velinov and A. Mileva, "Running and Testing Applications for Contiki OS Using Cooja Simulator," Int. Conf. Inf. Technol. Dev. Educ., pp. 279–285, 2016.

[22] A. Kumar and S. Gupta, "Study on ZIGBEE Technology," vol. 2, no. 10, pp. 297–301, 2013.

[23] I. C. Magazine, C. Gomez, U. Polit, and C. B. Universit, "From 6LoWPAN to 6Lo : Expanding the Universe of IPv6-Supported Technologies for the Internet of Things," no. January, 2017.

[24] M. Ramadany and D. Amegouz, "Diagnosis of the Integration Remote Monitoring System Based on Smart Sensors for a Production System : a Case Study Issues of Integration and Deployment of Smart Remote Monitoring System," vol. 10, no. March, pp. 152–158, 2017.