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An Application of Artificial Immune System in a Wastewater Treatment Plant

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Abstract: *Guaranteeing the continuity and the quality of services in network plants is a key issue in the research area of asset management. Especially when the plants are located in a wide area where machines are not continuously monitored by the operators. In particular, the pervasive adoption of smart sensors could be able to develop intelligent maintenance system through an elaboration of data coming from the machines: this data could be processed by diagnostics algorithms to warn preventively the fault status of the components or machines monitored. The algorithms' structure is contained in a multiple system of agents that have different tasks to manage both the single machine and the information exchanged within the whole system. This paper aims to present an application of Artificial Immune System defining, for each plant section, the kind of agents employed and the related sensors that must be adopted to collect the useful data. In order to provide a practical example, the structure of an Artificial Immune System has been implemented in a wastewater treatment plant where the agents are tested with noteworthy results.*

Keywords: Artificial Immune System, Intelligent maintenance system, self-healing, Wastewater plant

1. INTRODUCTION

Nowadays one of the most important challenge concerning asset management, is using new technologies to optimise operations and maintenance performances of the plants. Optimising the whole management of plants means increasing the level of automatization and devising systems that could prevent failures and related down time of the machines as well. In particular, one of major topics that are discussed within the academia and the industrial world is the development of adaptive systems able to auto-diagnose degradation from the well-functioning contextually allowing a self-healing of machine and equipment.

In this context, modern control system sensors have evolved from simple transducers of physical quantities to expert systems, capable to assess the measures carried out and to take the appropriate decisions autonomously. The widespread adoption of such sensors, widely known as 'smart sensors', has allowed an increase in the flexibility of the plants and, at the same time, a simplification of the cabling of the entire infrastructure (Smith et al.1995).

Particularly in the maintenance area, there has been an increasing adoption of Prognostics and Health Management (PHM) systems with the main purpose to change the maintenance practice from a "fix-and-fail" approach to a "predict-and-prevent" strategy (Lee et al.2011). Forecasting and preventing equipment failures can save time and money, besides increasing the operations reliability and safety (Scanff et al.2007).

However, such a thorough revolution cannot be achieved in a short time but it must be adopted through a step by step approach where the first step is the use of Condition Based Maintenance policy.

Condition Based Maintenance (CBM) is a management philosophy that posits repair or replacement decision on the current or future condition of assets (Raheja et al., 2006), assessed by monitoring equipment through sensors measuring physical variables (e.g. vibration, sound, energy consumption) associated with its performance. This information can also be used to forecast the remaining useful life (RUL) and optimise the maintenance schedule. Systems that implement these prognostic characteristics are also known as Intelligent Maintenance Systems (IMS) (Muller et al., 2008).

The adoption of CBM or more advanced prognostic techniques however usually requires a modification of the industrial plants in order to make the system able to acquire the required signal and to feed the maintenance algorithms.

The adoption of intelligent sensors leads important benefits on the overall performance of the plants. However, for maintenance purposes, the new available architectures are not effective yet, since the use of smart sensors can lead to the definition of completely autonomous plant areas and functions. A typical smart sensor has built-in enough computation power and I/O peripherals to control a set of actuators without the need to be interconnected; in this case, the data needed for maintenance operations may not be available to the whole maintenance system.

The widespread adoption of smart sensors has also led to the development of decentralised control systems and consequently to the development of decentralised IMS. The use of smart sensors in fact has pushed also a changeover of the traditional bus architecture due to the increasing adoption of IP-based fieldbus like EtherCAT or PROFINET (Felser et

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al., 2005). The use of IP as a common protocol allows an easy integration of the industrial networks with the other networks available on the facility and, consequently with Internet too.
This trend is further enhanced by the new standard for "wireless fieldbus". In this system, known as Wireless Sensor Network (WSN) (Spencer et al., 2004), (Lewis, 2004)it is possible to connect sensors, actuators, PLC, DCS and mobile devices in an easy way avoiding the cabling cost, that could be highly relevant in case of mobile devices.
In summary, nowadays CBM and Prognostic approaches can be clustered in two different sets, centralised and distributed, and are adopted by a larger number of plants. However, there is a particular set of industrial plants where the adoption of these methodologies is very difficult: the transfer systems.
The transfer systems are wide geographically dispersed applications, such as crude oil pipelines or wastewater treatment; in these plants the maintenance logistics has high costs and standard approaches usually lead to sub-optimal solutions.
These systems are composed by a huge number of devices, often placed in different areas and often without possibility of data connection. In such applications, autonomous IMS, capable to estimate their health conditions, can be used to forecast maintenance needs (e.g. time to fault, required supply parts and service personal) and to optimise maintenance schedule, therefore reducing the overall costs. Devices in such large distributed networks are activated very few times (once a day) and much time is needed to acquire data related to device behaviour directly on field.
In this kind of plants, the adoption of a standalone centralised IMS is limited by the training data acquired in lab, since fault modes related to environmental conditions may not be detected. On the other side, the lack of a reliable communication network between the different sections of the plants makes extremely difficult, or even impossible, the use of a classical distributed maintenance system.
The aim of this paper is to show an application of AIS System in a Wastewater Treatment Plant that allows to overcome the limitation of traditional maintenance approach in this specific case study. To solve this task a biomimetic approach has been used with the use of Artificial Immune System methodologies. These techniques allow to solve maintenance problems, and also other kinds of problems, by imitating the way of function of a biological immune system.
Furthermore, biomimetics has also been adopted for the implementation of the system, through the use of Multi Agent Methodologies, in order to mimic the distributed nature of an immune system.

2. LITERATURE REVIEW

This section is rather devoted to a review of the most acknowledged scientific proposals and industrial implementations of AIS. The first analysis regards the application domain in order to identify the fields where the use of AIS is currently under investigation and where researchers expect good results. Figure 1 shows how the application domain is distributed.

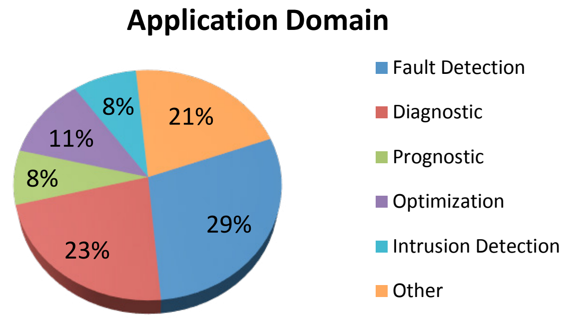

Fig. 1. Literature Review of the application domain

The most common use in industrial application is fault detection and diagnosis, a natural application to the pattern recognition and anomaly detection features of the AIS. Diagnosis is closely related to fault detection and some works use these two terms in the same sense. In particular, regarding fault detection, AISs are used mainly for weak signal analysis in order to perform the detection of a failure from the data provided by a set of sensors using black box approaches or to perform novelty detection often using negative selection methodology. On the other hand, for fault diagnosis, AIS are commonly used for fault identification, through the implementation of classifier algorithms.

Several studies apply the AIS to both tasks, like fault classification for rotating machines presented by Tang (2011) and by Strackeljan (2008). Other works use AIS to fault detection in combination with other techniques to perform the diagnosis, as the proposal of Amaral (2006) that uses a negative selection algorithm to detect the fault and a quad tree space partition to classify it. There are also works focused on fault detection, like the hardware immune system proposed by Bradley (2001) to perform error detection for reliability measurement or the new AIS proposed by Laurentys (2011), based on Natural Killer (NK) immune cells.

Another application domain for AIS is the optimisation problem: a remarkable application in this field is showed by Bhuvaneswari and Ramachandran (2010,2011), using AIS to implement a distributed control for a microgrid generation based on energy auction. An unusual application found in the survey is in mine detection: Sathyanath and Sahin (2002). introduce an AIS based on an Intelligent Multi Agent Model (AISIMAM) in order to optimise the control strategies for mobile robots dedicated to demining.

Applications of AIS in the maintenance field explores the robust pattern detection feature to perform mainly fault detection and diagnosis. The analysis shows that AISs are very common in literature in order to develop new advanced maintenance systems. This is mainly due to the performance and robustness that these methodologies reach in pattern recognition and other operations commonly used for prognostic and diagnostic.

The lines of investigations carried out within the literature review emphasise some relevant features on AIS, which deserve a better insight and attention for upcoming research in this field. In particular the main features of AIS are: