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Intelligent system for identification and replacement of faulty sensor measurements in Thermal Power Plants (IPPAMAS: Part 1)

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ABSTRACT

This paper describes a procedure of identifying sensor faults and reconstructing the erroneous measurements. Knowledge discovery in databases is successfully applied for deriving models that estimate the value of one variable based on correlated others. The estimated values can then be used instead of the recorded ones of a measuring instrument with false reading. The aim is to reassure the correctness of data entered to an optimization software application that was developed for the Thermal Power Plants of Western Macedonia, Greece. The architecture of the application follows the Multi-Agent System approach in order to cope with its complexity and distributed nature. The application was tested on a case study and proved to be efficient.

1. Introduction

Thermal Power Plants (TPPs) move towards incorporating systems that can help them to confront the challenges introduced by privatization and deregulation. From turbine upgrades, low-NOx burners, selective catalytic reduction (SCR) and flue gas desulfurization (FGD), to distributed control systems (DCSs), intelligent soot-blowing systems and advanced sensors these technologies address emissions, efficiency and reliability, and generate plentiful and valuable data about plant operations. The beneficial exploitation of these data and the complexity of all these newly introduced equipment necessitate the provision of intelligent tools that help the human operators to detect and cope with operational problems in real-time. To this direction, an optimization software application for the TPPs of Public Power Corporation (PPC) in Western Macedonia, Greece, has been developed. The Intelligent Power Plant engineering Assistant Multi-Agent System (IPPAMAS) is an integrated tool that extends from the sensor data validation to the provision of information and suggestions to the power plant personnel.

The IPPAMAS comprises of an off-line pre-processing and processing of data procedure, an on-line monitoring and an off-line re-training procedure (Fig. 1). Its central part, the on-line monitoring, is developed as a Multi-Agent System (MAS) that is structured in three layers: Sensor Layer, responsible for the identification and reconstruction of sensor faults, Condition Monitoring Layer, responsible for the safe operation of the Thermal Power Plant and its optimization, and Engineer Assistant Layer, which distributes the information to the appropriate users. The present paper is a detailed presentation of the first part of the software application, i.e. the Sensor Layer.

Sensor validation has been the subject of a vast list of papers found in bibliography. Typical approaches for the detection of incorrect readings of a sensor include the use of hardware redundancy and majority voting, analytical redundancy, and temporal redundancy (Frank, 1990). The difficulties, that each one of them presents, motivated the further research in this field, especially by using Artificial Intelligence techniques. Ibarguengoytia, Vadera, and Sucar (2006) reference some of them that apply mainly neural networks and fuzzy logic. They introduce a novel theory and algorithms for information validation based on the use of Bayesian networks utilizing probabilistic propagation to estimate the expected values of variables. Alag, Agogino, and Morjaria (2001) present a methodology for intelligent sensor measurement validation, fusion and sensor fault detection for equipment monitoring and diagnostics.

Since many proposed methods for sensor validation involve comparison of the predicted value with the available measurement of each sensor, fault reconstruction can be conveniently achieved by small additions. Principal Components Analysis and Partial Least Squares are applied for both identification of process and sensor faults as well as estimation of sensor values (Ritsie & Flynn, 2003). In other cases, fault signal replacement is not considered at all, whereas in several research papers it is included as a separate second part (Xu, Hines, & Uhrig, 1999). Neural networks have also been applied for sensor validation and estimation (Eryurek & Upadhyaya, 1990; Gribok, Urmanov, Hines, & Uhrig, 2004; Napolitano, Windom, Casanova, Innocenti, & Silvestri, 1998; Xu et al., 1999).

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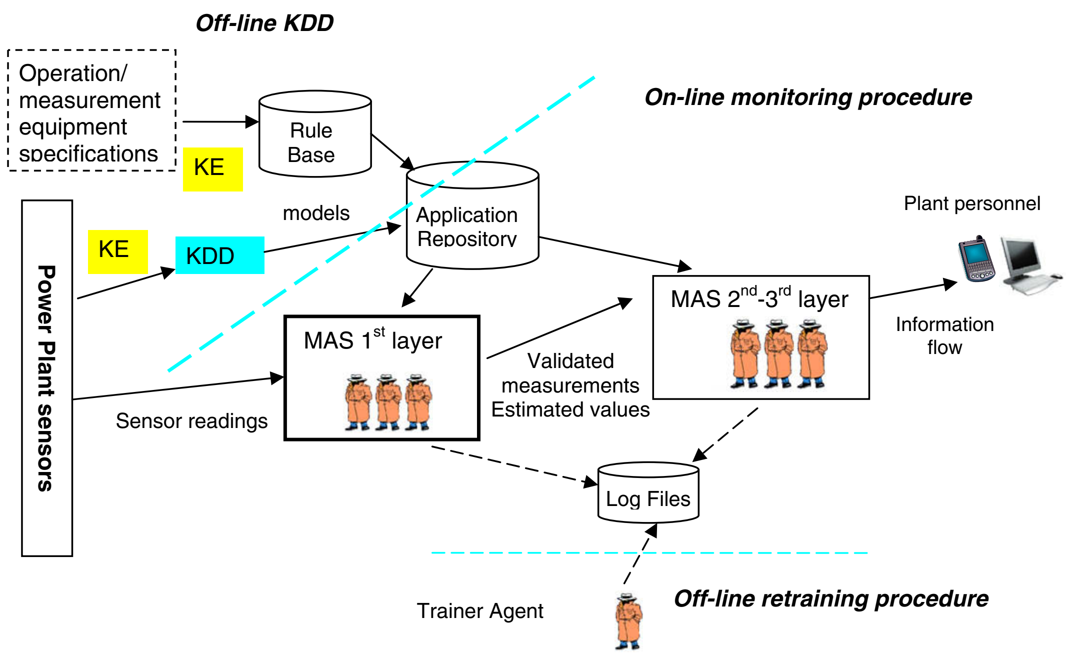

Fig. 1. The IPPAMAS architecture.

Multi-Agent Systems have been recognized as an emergent technology suitable for the development of complex, distributed applications. Several research projects investigated the possibility MAS applications to be adopted by the industry. ARCHON was the first well-known framework, based on MAS, to support the development of Distributed Artificial Intelligence systems in industrial domains, including the energy industry (Varga, Jennings, & Cockburn, 1994). Recent publications report successful case studies of MAS addressing specific issues of power plants control monitoring (Arranz, Cruz, Sanz-Bobi, Ruiz, & Coutino, 2008; Mangina, 2005).

The various methods for sensor validation have serious drawbacks in practice (increased demands in human expertise and computer resources, time consuming, etc.). This holds even truer for the present application considering that sensor validation comprises only the first part of it.

At the current project it was decided to base the validation on rules that derive from the measuring equipment requirements, the plant operation specifications and the personnel experience.

The main aspect is to reassure that data entered to the following stages of the optimization software are correct and that production of false alarms is minimized. The latter aims at preventing disorientation or even scorn caused by repeated display of false alarms.

There is a considerable number of papers in the literature concerning sensor values estimation [5–9]. The authors believe that for this purpose it is worthwhile to spend the demanded time and computer and personnel resources, contrary to sensor validation. Data mining (dm) algorithms are applied for deriving models that estimate the value of one variable based on others used as input parameters. The estimated values can then be used instead of the recorded ones by a measuring instrument that is out of order. The rules identifying erroneous measurements and the dm models are used by software agents during the on-line monitoring procedure.

The proposed method of sensor validation and the following replacement of the erroneous data constitutes the most significant contribution of the Sensor Layer to the overall application.

In Section 2 the system's architecture is outlined. In Section 3 the suggested procedure for sensor validation is presented. In Section 4 the methodology for sensor estimation is described. The applied data mining algorithms and attribute selection filters are listed and tables with representative results are given in Section 5 as a case study. Section 6 includes the main points of the MAS. The results of simulation tests are presented in Section 7 and the conclusions are stated in Section 8.

2. IPPAMAS architecture

The IPPAMAS aims at optimizing monitor and control systems of TPPs, acting not as a stand alone application, but rather as an add-on to the existing infrastructure. In this direction, the following were applied: (1) Knowledge Engineering for modeling the problem and identifying the suitable parameters, (2) Knowledge discovery in databases (KDD) for handling the huge number of operation data, and the fact that there is no known equation relating them and (3) Multi-Agent System to encapsulate the extracted knowledge to agents. These agents form the base for developing a complicated and distributed system that represents the procedure of operation control and ensures the appropriate information flow to the plant personnel.

The first part of the IPPAMAS takes place off-line. A KE methodology, Common-KADS is applied in order to convert the tacit knowledge of plant experts to explicit knowledge (Shreiber et al., 2000). Through this procedure the rules concerning the validation of data are expressed. In addition, Common-KADS takes advantage of domain knowledge so as to reduce the search space and eliminate the risk to find patterns statistically significant but with limited physical meaning. This contributes to the successful fulfilment of the KDD steps aiming to extract the appropriate models that will be finally embedded in the MAS.

The MAS comprises the central part of the IPPAMAS and is structured in three layers; Sensor, Condition Monitoring and Engineer Assistant Layer (Fig. 1). The layers are connected as input–output successive components. Each of them is autonomous, i.e. it can produce the appropriate results provided it has the right input. The three layers can be applied together or separately, depending on the needs of a TPP.