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ADVANCED MONITORING AND DIAGNOSTIC SYSTEM 'AMandD'

Keywords

Supervisory systems, distributed systems, decision support systems, diagnostic systems.

Abstract

The paper presents the structure and functional properties of the Advanced Monitoring and Diagnostic System 'AMandD' dedicated for large scale industrial processes. The system arose within the framework of research project 'CHEM' of 5th European Framework Programe. Up-to-date algorithms of modelling methods and fault detection and isolation applied in the system were described in the paper. Also a brief description of used IT solutions was presented. As a conclusion, the further direction of expansion, development and research were depicted.

Introduction

Advanced Monitoring and Diagnostic System AMandD arised as a result of a work conducted within the framework of the EU project "CHEM –Advanced Decision Support System for Chemical and Petrochemical Industry" (www.chem-dss.org) and the work of the Institute of Automatic Control and Robotics (IAiR) of the Warsaw University of Technology (WUT). The aim of the CHEM project (2001-2004) was to develop an environment and algorithms of the advanced decision support system (DSS) for the chemical and petrochemical industry. The elaborated software has an general nature and can also be implemented in other industry branches. Currently works on extending AMandD system are supported within the framework of the research task ”Anvanced diagnostic system and device for technological apparatus and processes, no. PW-004/ITE/07/2005” in The Multi-Year Programme entitled “Development of innovativeness systems of manufacturing and maintenance 2004-2008”. The paper presents a general description of the AMandD system.

1. System functions

At the beginning AMandD was created for two issues: diagnostics of complex industrial processes and identification and simulation of parametric models for the reconstruction of the selected process variables. During development additional functions were added. Finally, a system that allows realisation of advanced monitoring and diagnostics of industrial processes has been achieved. The AMandD system plays a superior–advisory role in respect to the control system. The following functions are available in the current version:

- **Modelling and simulation** with the use of process data driven parametric models, as well as models based on the physical phenomena, e.g. balance models. The system provides tools for the design of model structures, parametric model identification and on-line simulation.
- **Process variable processing** in a freely configurable environment with the application of user defined processing paths based on available functional blocks. It is possible to implement practically any algorithm, e.g. configuring balance and efficiency calculation systems.
- **The realisation of process software simulators.** It is a special use of modelling and simulation for the creation of complex systems software simulators purposes. Such simulators can be used, e.g. for the optimisation or operators training.
- **The realisation of software sensors and analysers.** With the use of models, the process variable values reconstruction is performed. It is possible to restore measurements that are temporary unavailable (e.g. due to sensor fault), as well as those which are inaccessible in on-line, real-time mode (e.g., flammable parts content in ash).
- **Fault detection and isolation.** The system enables to realise diagnostic algorithms for abrupt and incipient faults of sensors, actuators and technological components. Applied algorithm implements a fuzzy evaluation of diagnostic test results and fuzzy reasoning. The application of fuzzy logic enables taking into account several kind of uncertainties that are connected with diagnostic reasoning. In particular cases the system can trace the state of slowly developing device degradation.

- **The visualisation** of diagnosis results, simulations, etc., with the use of build-in module of graphical visual process data presentation.
- **Operator decisions assist and diagnosis propagation.** In the abnormal and faulty conditions predefined instructions, procedures and helpful announcements can be automatically delivered to the operators. It is also possible to send selected information through e-mail and SMS services.

Further development activities are also conducted. They are connected with the following: the archiving of process and system variables, including diagnosis; advanced diagnosis management, including their justification; diagnostic report generation; making system data available through a web browser; elaborating generic database of process components. The functionality of the AMandD system can be easily extended due to its open architecture and the application of modern software technology (e.g. *plugins*). The creation of specialized modules for specific application and scalable solutions is also possible, e.g. the system of control valve diagnostics or power boiler systems. Such solutions take into account the specific process nature with a higher degree. They can also guarantee an easier configuration and further maintenance.

2. System modules

The AMandD system consists of several modules assigned to realize independent functions. Modular structure of the system allows the distribution of AMandD to different PC's connected with LAN, makes the whole system flexible and easy to expand. All modules, from the software point of view, are stand-alone programs or services running under MS Windows. However, calculation modules without GUI can be easily be adapted to another platform / operating system. Available modules can be divided into the following groups: input/output, calculation, utilities and others.

Input/Output modules are used for communication with external data sources. There is a possibility to connect via OPC servers (OPCLink) and via OLE DB (OPCLink). The dedicated modules can be elaborated, if there is such a need, e.g. a communication module dedicated for SCADA OSA-2 system (OSALink).

Calculation modules are the core of the system. Actually, all system functionality is now implemented in one calculation module CalcPaths. It is an open, freely configurable module with GUI similar to Matlab Simulink (Fig. 3). With the help of CalcPath, there is the possibility to create complex signal transformation paths. A wide range of libraries of transform blocks available consist of basic math functions, math parsers, statistical and logical operators and the set of specialized functions to design diagnostic tests algorithms. Also a special library used to simulate parametric partial models identified with use of MITforRD during off-line configuration stage is available. Another specialised library is responsible for the diagnostic reasoning - fuzzy residual evaluation and fault isolation (iFuzzyFDI RTFI).

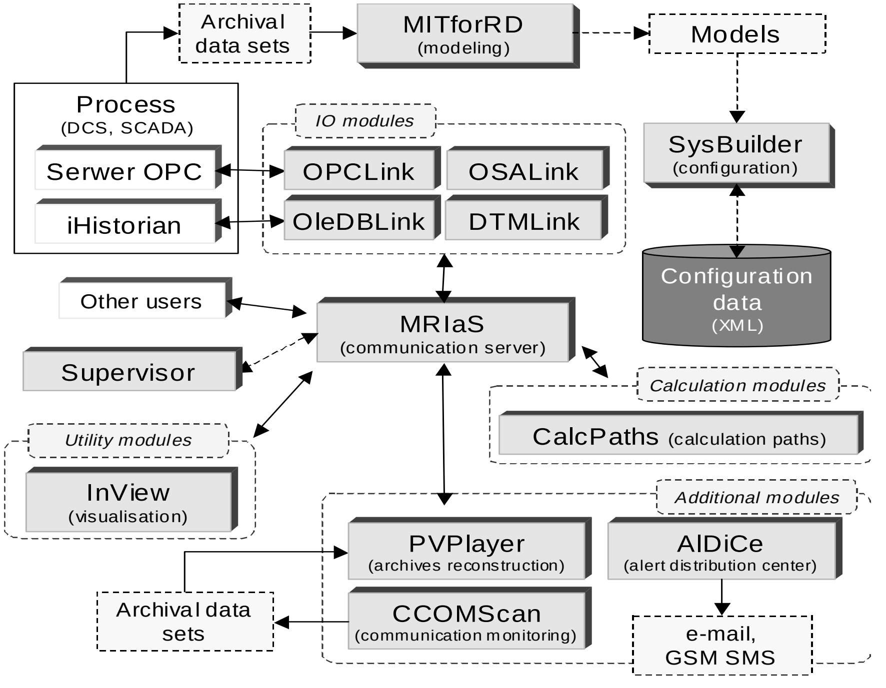

Fig. 1. Basic AmandD system modules

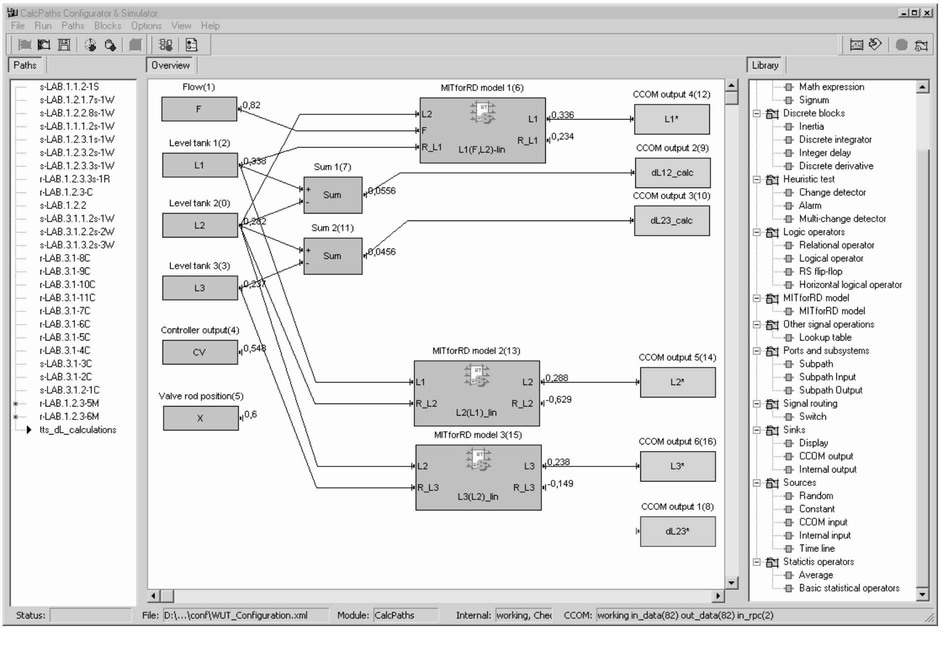

Fig. 2. Process variable transform module – CalcPaths

Utility modules are used in real time to communicate with the user. The main module in this section is InView - native AMandD visualisation. This module allows to freely configure displays of process variables on the set of process mimics and user defined screens.

Additional modules are designed to realise specific functions outside the scope of the main system tasks.

An important part of the system is **M**ITforRD Model Builder. This is an advanced software package developed for the off-line model identification based on archival data sets. A more detailed description of this module is given in section 3.

3. Modelling and simulation

The creation of the models of the whole process or its parts is needed for the on-line diagnosis of technological installation and advanced control algorithms of industrial processes. The models that faithfully imitate the run of a real process are also needed for the installation of work optimisation, new control strategies tests or operators training purposes. The models of a much smaller scale, reconstructing single process variables (e.g., model of a CO_2 content in the waste gas or the temperature in the reactor) can be used as an analytical redundancy. Such redundancy is used for fault detection and virtual sensors and analysers purposes.

In the AMandD system the MITforRD module is used for the identification of models that reconstruct particular process variables. This module enables the creation of models based on archival process data sets without the necessity of knowing the analytical structure of the relations between process variables. MITforRD enables identifing the static as well as dynamic models of different types. The following type of models have been implemented so far:

Linear difference equation (discreet transfer function). The identification is conducted based on minimizing of LS criterion with the use of SVD algorithm and with automatic search for best model rank and delays.

Fuzzy TSK models with polynomial consequent functions which is a unique solution. The automatic identification of structure, fuzzyfication parameters and all model parameters is possible with the use of specialised evolutionary algorithm.

Artificial neural network models with a classical structure of multilayer feed-forward perception. Different kinds of network learning are available (e.g. back propagation, simulating annealing, conjugated gradients, genetic optimisation).

An easy extension of the available model types is possible due to the open module architecture based on ‘plugin’ technology. The software supports all model building phases: preparation and validation of measurement data, identification process and achieved models verification and comparison.

In the scope of archival data preparation the module deliver extended functionality that enable, among other: data export and import, data selection and edition, advanced graphical representation in the form of time series (advanced zoom, multi-variable displays, etc.) as well as data analysis and pre-processing (correlation, power spectrum, histograms, trends, filtration, freely define calculations thanks to particular mathematical expression, etc.).

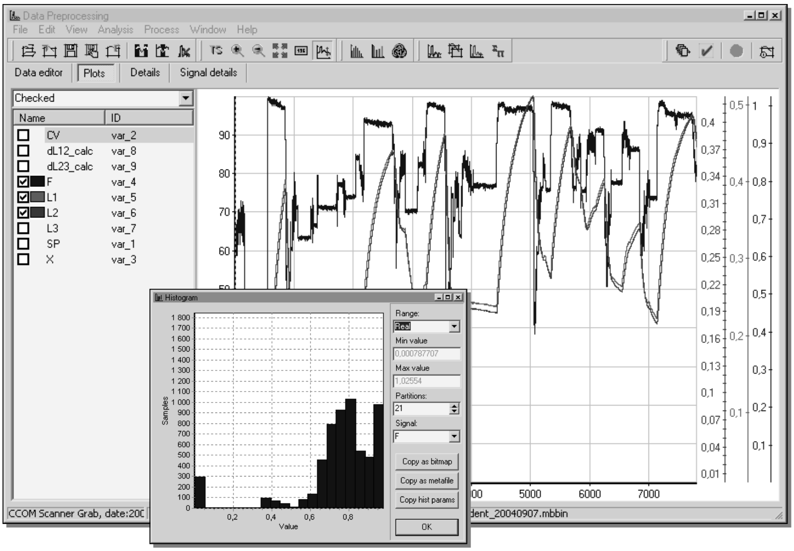

Fig. 3. Data analysis and preprocessing in the MITforRD Model Builder module

The model identification procedure is supported by wizards which guide the users - the user must only answer some simple questions (e.g. the selection of input signals, model type and basic identification procedure parameters). To decrease the identification procedure, the calculations can be spread among several PC’s connected with the Ethernet. In order to do it, a special, distributed, auto-configurable and very easy to use environment is available. The package enables simultaneous models simulation for selected test data set in the field of models verification. One can evaluate models in a qualitative way based on the time series representation or can use more advanced analysis. It enables the choosing of the best model for a particular purpose.

4. FDI algorithms

Several kinds of uncertainties are connected with the diagnosis of industrial processes. They make the diagnostic reasoning procedures much more difficult. The fault symptoms can be uncertain. It is hard to define thresholds that testify to fault existence. The expert knowledge about the relation between faults and observed symptoms is also very often uncertain. All the above uncertainties can be taken into account in the FDI algorithms of the AMandD system. This algorithm implements fuzzy logic for residual evaluation (diagnostic tests) and diagnostic reasoning. The general scheme of fault detection and isolation algorithms implemented in the AMandD system is presented in Fig. 6.

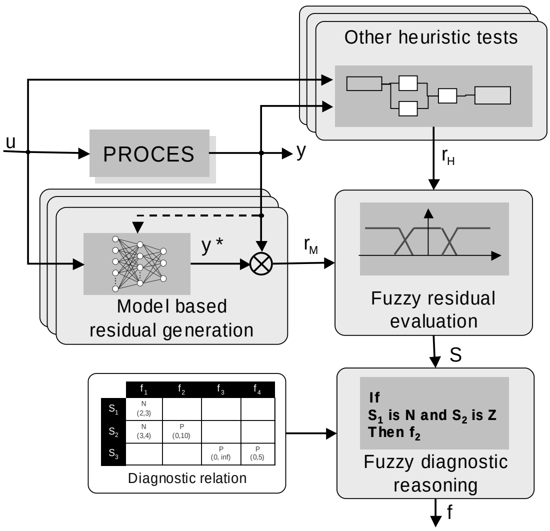

Fig. 4. Diagnostic scheme used in AMandD system.

4.1. Fault detection

The detection algorithms are based on the analysis of the current process variables (u, y). They are configured by the user and performed by the CalcPaths module. The diagnostic tests can be divided into two main groups. The first one constitutes model-based residuals (r_M). They utilise all kind of models mentioned in the previous section. The second group (marked as r_H) consist of all other diagnostic tests (usually called heuristic ones). They utilise such elements like the following: the knowledge about the relation between process variables, process balance equations, hardware redundancy, etc. The design experience shows that such relations constitute a very essential and reliable source of information on the process condition and the existing faults. The knowledge about this relation is usually possessed by the process and control engineers, as well as by operators. The AMandD system delivers tools to its coding in the algorithms and utilisation for on-line current process diagnosis. The application of the various detection techniques enables detecting a much higher number of faults in comparison to classical alarm systems. The sensitivity of these methods is an additional advantage. It enables, in many cases, an early detection of a petty faults (e.g. valve seats sedimentation, the beginning of parasitic reaction in the chemical reactor) before its negative effects disclose.

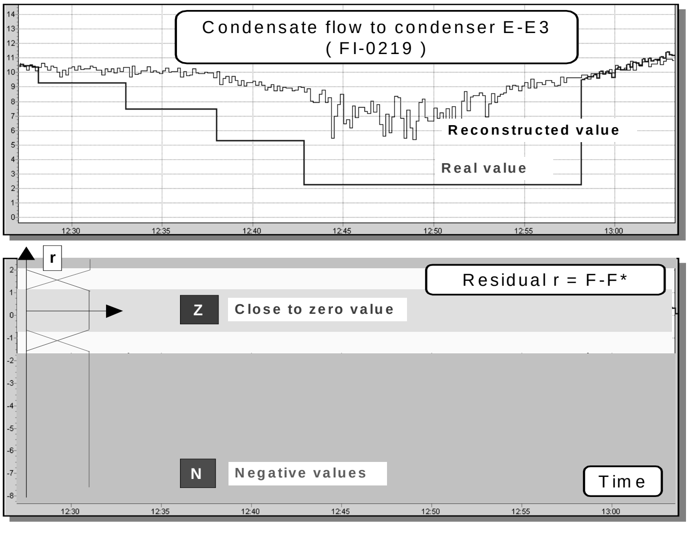

Fig. 5. Fault detection of the control vale of condensate flow to the condenser E-E3 in the area installation in the Nitrogen Factory ”Puławy S.A.”. The top figure shows real and reconstructed flows. The bottom one displays calculated residual.

The evaluation of a diagnostic test result can be fulfilled in a crisp or fuzzy way [1, 2]. Crisp evaluation is used when the uncertainty of the test result do not need to be taken into account, e.g. algorithm of a test written in the form of Boolean expression. Fuzzy evaluation is used when due to problems like modelling uncertainty, measurement noises, the insufficiently precise knowledge, etc. uncertainty of the test result should be considered. In both cases, multi-valued evaluation can be used. Three-valued evaluation is used when, due to higher fault insolubility, the sign of a residual (test result) should be taken into account. The fuzzy set parameters can be determined automatically, based on statistical parameters of residual time series in a fault free state or manually by the system operators.

4.2. Fault Isolation

The methods of fault isolation that require data sets for abnormal and faulty states (e.g. neural networks) for its configuration pattern are practically useless in the case of industrial installations diagnosis. Getting this data for all abnormal states (states with faults) is practically impossible. On the other hand, danger faults that occur for the first time should be quickly detected. The methods that utilise expert knowledge for the design of the diagnostic (fault-symptoms) relation play the most important role in the practical applications of industrial processes diagnosis [1]. Such an approach is used in the AMandD system. Fuzzy diagnostic reasoning [2] is performed on the basis of the analysis of the current diagnostic signal values and written in the rule base relation. This relation is described by the rules that are presented in the form similar to natural language. Such rules describing the relation between pattern symptoms (values of the diagnostic signals) and particular faults, are defined by the expert during system configuration in the following shape:

$$If\ (S_1\ is\ N)\ and\ \ldots (S_j\ is\ P) \ldots (S_J\ is\ Z)\ Then\ (f_k) \qquad (1)$$

The proper reasoning, realised by specialized function blocks of iFuzzy-FDI library available in the CalcPaths, is realised according to the iDTS method (Industrial – Dynamic Table of States) [3]. This method is a combination and extension of DTS, F-DTS and T-DTS methods elaborated by the IAiR WUT. Its main features and advantages can be characterised as:

- a possibility to take into account different kind of uncertainties [2],
- a possibility to take into account symptoms dynamics (delay) to increase fault insolubility and limit the appearance of false diagnosis,
- a serial-parallel inference that enables to formulate current diagnosis in each step of reasoning,
- the use of dynamically created isolation threads to decrease the possibility of false diagnosis elaboration and to enable the isolation in the case of multiple faults scenarios [4],
- the use of the two-level hierarchical reasoning structure with decomposition possibilities,
- automatic reconfiguration in the case of varying the set of available measurements, reliable diagnostic signals and previously identified faults.

As a result of reasoning, the system generates the set of fault presence certainty factors (f) which formulate the final diagnosis about the system state.

5. Pilot applications

The first, not yet fully functional, version of the AMandD was applied in pilot applications for the diagnosis of selected parts of the IDR section in the carbamide plant at the “Nitrogen Factory Puławy S.A.” and for the laboratory-scale installation of steam generator at the Lille University. In the IDR section the following components were diagnosed: media temperature measuring paths within the reactor, steam condensate flow sensors and actuator units in the condensers. The full diagnosis of sensors, actuators and process components were realized in the case of a steam generator. The most complete application was realised in Lublin Sugar Factory at the end of 2004 [5]. The system conducted the diagnostics of fresh juice heaters and the first three sections of the evaporation station. The selected sensor, actuator and components faults are taken into account (more than 50). Almost 50 diagnostic tests are designed for FDI purpose, most of them are heuristic ones (27 diagnostic tests, 6 model-based).

6. Further development and research

The AMandD is an advanced diagnostic system of complex, large-scale industrial processes. Its practical usability is shown by means of conducted tests for the laboratory stands, as well as for real production processes. Of course, system functionality applied in the AMandD does not use up all of the tasks connected with the advanced monitoring and the diagnosis of industrial processes. Further system development in the FDI field as well as in other related ones are planned. This expansion is possible due to modular system structure and flexible calculation environment with build-in plugins technology. In the scope of modelling, the issue implementation of successive models and identification procedures is planned (e.g. the implementation of particle swarm optimization). In the field of FDI techniques the main afford will be put on the following: the extension of detection algorithms (among others, tracking the development of incipient faults and its identification), automatic adaptation of fuzzy diagnostic tests (residual) evaluation parameters, further development of isolation algorithms (problem of multiple faults, taking into account the symptoms appearing sequence) and tools supporting the diagnostic relation design stage. There is also a development work indirectly connected with identification algorithms and FDI tasks conducted. The support of the configuration stage with the use of the following tools is considered: specialised components database, the analysis of cause-result graphs for the optimal selection of diagnostic tests structure searching and diagnostic system decomposition. The modules of operator decision support, diagnosis propagation, data archivisation and WWW services are also developed. Also the embedded versions of the selected system modules are under development. They will be used to build independent diagnostic devices.

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System zaawansowanego monitorowania i diagnostyki AMandD

Słowa kluczowe

Systemy wspomagania decyzji, nadzorowanie, diagnostyka uszkodzeń, symulatory procesów.

Streszczenie

W artykule zaprezentowano strukturę oraz właściwości systemu zaawansowanego monitorowania i diagnostyki procesów przemysłowych AMandD. System ten powstał w ramach projektu badawczego „CHEM", realizowanego w ramach 5 Programu Ramowego Unii Europejskiej. Omówiono wykorzystane w systemie nowoczesne algorytmy i metody modelowania oraz detekcji i lokalizacji uszkodzeń oraz zastosowane rozwiązania informatyczne. Przedstawiono także kierunki prowadzenia dalszych badań oraz rozwoju systemu.