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Intelligent Agent-Based Monitoring Platform for Applications in Engineering

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Abstract: In real world monitoring engineering applications, knowledge engineers must face the complexity and diversity of tasks associated with specific problem domain. This often implies tackling simultaneously different types of knowledge (inaccurate, incorrect or redundant) from different data sources that require to be processed using different reasoning mechanisms. The real world problems may neither fit the assumptions of a single technique nor be effectively solved by the strengths and capabilities of a single technique. Within this paper an intelligent agent-based platform is being considered for implementation, where the approach of integrating the use of two or more techniques is taken, in order to combine their different strengths and overcome each other's weaknesses and generate hybrid solutions. The integration of various intelligent techniques is a very important way forward in the next generation of monitoring systems. Flexible software systems require a distributed architecture where each element works autonomously and co-operatively. This advanced architecture can be created by making use of Intelligent Agent technology, which will facilitate the creation of autonomous software components to utilize a wide variety of artificial intelligence techniques for different situations. This is in marked contrast to conventional centralized stand-alone applications.

1. INTRODUCTION

In recent years the need for improved monitoring systems has necessitated the application of intelligent systems. The main issues to be considered are the availability, reliability and maintainability of the equipment to be monitored. With continuous monitoring, failure can be delayed or even avoided (Williams, 1992). Intelligent condition monitoring has been described as the assessment of the current condition of equipment (or part of it) by the use of intelligent techniques, which can range from sophisticated computer-driven instrumentation to Artificial Intelligence (AI) based data classification methods {see (Mangina, 2000); (Warwick, 1997); (McDonald, 1997); (Georgin, 1995) and (Moradian, 1991)}. The main target is to predict failure, monitor certain parameters and to economically perform maintenance only when a potential failure is identified and at a time convenient to the schedule. Along with maintenance of equipment, knowledge extraction from the data provided during the monitoring process is of high importance. Problem solving, prediction of possible faults and cases (or scenarios) extracted from certain parameters' correlation, which in any other case could not be noticed from human operators could be solved using an advanced automated solution (Jennings, 1993). The main objective of this paper is to discuss the development of an intelligent monitoring platform for computer-aided monitoring, simulation and diagnosis based on the leading edge technology of intelligent software agents (Wooldridge, 1995). The proposed framework utilizes different AI techniques and data classification/clustering methods {see (Mangina, 2003a) and (Mangina, 2001a)}. The system will apply the novel hierarchical architecture COMMAS (Condition Monitoring Multi-Agent System) (Mangina, 2002a), (Mangina, 2001b). The concept of agent-based monitoring has been applied in different areas by the author (gas turbines monitoring, gas insulated substations - in power industry - and production of gellan gum - in bioscience) {see (Mangina, 2003b); (Mangina, 2002b); (Mangina, 2002c); (Mangina, 2001c); (Mangina, 2001d); (Mangina, 2001e), (Mangina, 2001f); (Mangina, 2001g) and (Mangina, 2001h)}. Through this framework a unified, application-independent, standardized approach is aimed. The development of such a platform will cover the needs of data classification, clustering, monitoring and, finally, diagnosis and knowledge extraction for projects within a variety of areas (environmental, medicine, health care, agriculture etc.) {see (Mangina, 2004); (Mangina, 2003c); (Mangina, 2003d); and (Mangina, 2002d)}. Furthermore, but equally important, another aim of this platform is the maintenance of the valuable knowledge of the experts in certain areas in an electronic form (Mangina, 2001d). The platform will have the functionality of extracting, and modelling experts' problem solving procedures, as well as updating them with new knowledge that might have been discovered from the intelligent monitoring procedure. In many cases the increasing volume of different types of measurement data and the pressure to human experts to identify faults quickly might lead to false conclusions. This sets the requirements for an advanced automated solution, which is proposed within this paper. Within the analysis, design and implementation of the intelligent monitoring platform for engineering applications, the main objectives to be achieved can be summarized as follows:

- Design and implementation of different data classification and clustering methods to provide effective knowledge acquisition and knowledge extraction for different problem domains.
- Development of techniques for monitoring problem solving procedures.
- Development of algorithms and methodologies for knowledge management and human problem solving simulation.
- Realization of a working software platform integrating the above with a user-friendly graphical interface.

2. CASE STUDY FOR GIS

Within this paper the application of agent-based technology in advanced condition monitoring for data interpretation of a large volume of data from a Gas Insulated Substation (GIS) is described, which has been a successful case study for agent-based data interpretation and monitoring. Interpretation of the parameters is complex but essential to assess possible performance deficiencies. By measuring these parameters on-line, the data can be gathered in a form that is ideal for the application of an intelligent agent-based monitoring system, which will select the most appropriate interpretation technique under varying operational conditions. The analysis of recorded signals could be simplified and automated through the application of classification tools and the use of intelligent agents, which apply Artificial Neural Networks, K-means clustering and C5.0 rule induction method. This software system can enhance the capability of the partial discharge detection system by adding new intelligent tools specializing in the recognition of partial discharge sources.

2.1 Partial Discharge(PD) diagnosis within GIS

Partial discharge (PD) is the electric phenomenon where small voltage and current pulses are generated by fast electrons and ions in electrical insulated systems. In extra high voltage gas insulated equipment, PD occurs when a defect (i.e. small protrusion on the inner conductor or a free metallic particle) enhances the local electric field. The electrical and chemical activity associated with the presence of such defects may lead to significant degradation of the insulation and sometimes to complete breakdown (Schlemper, 1993). There are various types of defects that can cause Partial discharge. Commonly found defects fall into the six main categories quoted below:

- Free particles: when detached metallic particles are liable to the AC voltage cycles, they hop at the bottom of the chamber and emit very fast current pulses.
- Busbar protrusion: sharp needles on the high voltage electrode cause partial discharge with a corona effect.
- Chamber protrusion: same as above but the needle is on the enclosure.
- Floating electrode: this is particular to situations where one of the electrodes has one part, which is not directly connected to the main body. Sparks cross the gap between the two components.
- Surface contamination on insulating barrier: metallic particles that are glued on to the surface of the spacer may cause surface discharge.
- Cavities in insulating barrier: internal voids trapped in the insulating material can initiate partial discharge.

Not only do the standard defects need to be monitored, but also external sources that can be detected by the actual system like communications noise, radar signals and motor noise and any other external source whose signal can be detected.

2.2 Intelligent Agents for GIS monitoring

Following the data preparation and the evaluation of different classification techniques, there could be identified cases for the GIS, where one individual method could not classify the type of defect accurately, or could identify only certain type of defect. Consequently, a number of software entities have been developed and form the hybrid solution for COMMAS-GIS (COndition Monitoring Multi Agent System for GIS) (Mangina, 2000), the generic framework of which is given in Figure 1. The different software agents, which interact in a dynamic way to support the required data interpretation functions include:

- Kohonen-map agent: classifies data using Kohonen maps;
- Kmeans agent: classifies data using Kmeans clustering algorithm;
- C5.0_rule_induction agent: classifies data using rule induction;
- Case Based Reasoning (CBR) agent: reasons based on past cases of the same type of defect;
- Meta_Knowledge Reasoning Agent: gathers the information from the data processes from the previous agents and informs the EAA;

- Engineering Assistant Agent (EAA): informs the user of the final result with details based on the users' profile.

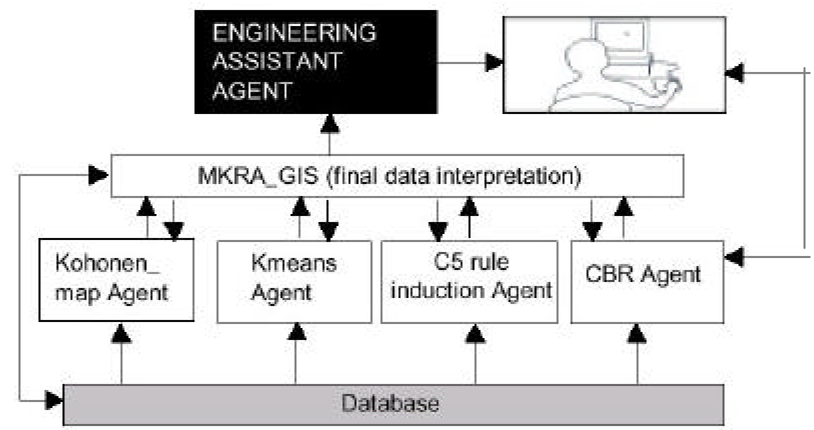

Figure 1: General system architecture for GIS monitoring

For the software development of this case study there have been developed 5 different types of intelligent software agents, while the number of the EAA depends on the number of users. Monitoring the PD signals and interpretation of the parameters is complex but essential to assess possible performance deficiencies. The coupler within the GIS detects the signal, which is then sent to the diagnostic monitoring system. The "fingerprint" representation of the partial discharge record, as described previously, is based upon statistical analysis of the raw data. This reduces the amount of data to be stored, and picks out the salient features within the data. Within this application there were approximately 600 different cases in the database covering 7 distinct classes (types) of defect. The data provided to the software system are in the form of text files to be read and processed from the intelligent agents:

- <Casename, Feature 1, Feature 2… Feature 30 >

COMMAS-GIS will identify new cases based on the most appropriate classification technique by calling the different classification agents. The software system has been implemented using agents' technology, where each agent individually interprets and classifies the data using its embedded technique, and communicates its results using KQML (knowledge Query Manipulation Language) messages. The training of each algorithm has been implemented off-line, and the accuracy of each method has been evaluated from the agents, which call the external programs responsible for testing. For each unidentified new case, the agents execute each method and the final result is the outcome of their combined interpretation (based on the "majority voting system"). Within each type of classification agents (Kohonen_map, K-means, C5.0_rule_induction) each clustering algorithm has been implemented to classify the data based on the classification role model. Although each classification agent is using a different method (by calling different external programs), they all belong to the same role model, because the database has to be accessed and after (off line) training, the accuracy is calculated. For the identification of each case the results are sent to the MKRA_GIS to be processed and the EAA informs the user of the procedure in detail. Each type of agent embodies the final vector of weights or rules from the training executed off line. The testing and the accuracy evaluation are accomplished on line from each classification agent. During discussions with the experts it was identified that there are certain characteristics of each type of defect that could be seen from the 3D display provided by the existing monitoring system. These allowed the expert to come up with a conclusion on which type of defect a case belonged to. For example, certain defects tend to appear at certain times, or phases. The expert would therefore look at parameters like time and phase dependency. Any symmetry that existed within the pattern on both the negative and positive cycle would provide information about the physical reality of the defect. To emulate the experts' reasoning, representative cases of each defect could be identified, which would then be provided to the user through the Case Based Reasoning (CBR) software agent within the COMMAS-GIS. Along with the fingerprints for each case, the 3D display from the raw data is stored to be used by the CBR agent, to display it to the user. Based on the given images the user will select which one is the most similar and will give feedback to the CBR agent along with the confidence factor representing the user's belief of the new case being of a certain type of defect. The result will be sent to the MKRA_GIS and the new case will be stored to the case memory of the agent and will be used for testing another new case in the future. The impact of the CBR agent to the overall multi-agent system is of high importance, especially for cases where the software system cannot identify and there is the need for the experts' input. The feedback from the experts is then stored in the case memory as new cases and the knowledge can be reused and the accuracy of the system will be increased over time.

2.3 Results

This case study has presented the analysis undertaken upon GIS Partial Discharge monitoring data using clustering and classification techniques. The Kohonen map can be used successfully to classify most of the data classes by assigning a class identifier to each neuron in the map. The K-means clustering algorithm had a very good performance as it could accurately classify the input data according to which cluster the data is nearest. The C5.0 performance is comparable to that of the Kohonen map, where again certain classes could not be differentiated from the other classes and it provided rules, for future rule-based intelligent system implementation. Although most of the classes could be identified using the previous techniques, problems were encountered due to an uneven distribution of the data between the classes. Provided more data the different techniques will be used and evaluated again. Next stage of implementation for COMMAS-GIS could be to embed knowledge elicited from experts who manually analyze the PD signals and to integrate it with knowledge based systems to emulate the experts reasoning.
This will allow tacit expertise gained over many years to augment the existing classification techniques. The results from the initial discussion with problem domain experts lead to the following conclusions:

- There is phase dependency associated with most of the defects. Symmetry in the patterns on both negative and positive cycle gives information about the physical reality of the defect (e.g. floating electrodes cause discharges during the first and third quarter).

- There are specific differences between some of the defects (e.g. protrusion on busbar has the exact reverse pattern of that of a protrusion on enclosure).
- There are similarities between defects (e.g. floating electrode has quite a small signal because it is like a particle discharging).
- Digital interference (noise) can be easily identified due to the "blanket effect".
- There might be the case where two or more defects occur, which makes the identification more complex.

The agent-based approach offers a flexible condition monitoring architecture, which can be applied to other plant items. The distribution of the intelligence allows for scalability and ease of integration of new intelligent reasoning modules. Although currently only fingerprints of the PD signal data can be analysed the software system can be extended to monitor other parameters in association with other techniques of intelligent reasoning.

3. DISCUSSION

The availability of measurement data from monitoring processes, independently from the application domain, is increasing in quantity, quality and scope. The areas, where improvement can be made, have been identified (Mangina, 2003c) and provided the motivation of this paper for discussion:

- The number of plant specialists skilled in monitoring processes is limited. The need for development of sophisticated intelligent monitoring systems to simulate the experts' way of reasoning is required (McArthur, 1996).
- Specialists might require additional sources of effective diagnostic guidance, in order to support operational decision-making, particularly when under severe time pressure (Gemmel, 1995).
- Although modern monitoring systems provide operators with immediate access to a range of raw plant data, only application domain specialists with clear diagnostic knowledge are capable of providing qualitative interpretation of acquired data; an ability that will be lost when the specialists leave (Chorafas, 1990).
- In many industrial applications, the vast amount of data and complex processes associated with on-line monitoring resulted in the development of complex software systems, which are often viewed as isolated, non-flexible, static software components (Jennings, 1996), (Jennings, 1993).

One of the scientific benefits of a domain independent software platform for intelligent monitoring is the inclusion of a set of software tools for professionals involved in computer-aided monitoring of processes. The tools developed and embedded within the platform will enable engineers and scientists to model the monitoring processes and to predict the performance of these processes for various equipment configurations and operating conditions. The outcome of this research will be a standardized intelligent monitoring platform that covers the main application areas of Biotechnology. Although several attempts have been introduced for intelligent monitoring systems, the research literature and references attached with this paper can justify the fact that no standardized platform problem domain independent exists and also those efforts that have been implemented and used are not flexible, but domain dependent {see (Brust, 1997); (Cockburn, 1996); (Cozien, 2000); and (Jennings, 1998)}. Central to this research will be the use of knowledge elicitation, modelling and archiving in parallel to the knowledge extraction from the data classification and clustering methods embedded in the agent- based software platform (Mangina, 2001d). Within the research plan of the project platform, the following tasks have been identified:

- Analysis and design of intelligent agent-based monitoring platform: Following the standard methodologies for agent-oriented software engineering [GAIA (Wooldridge, 2000), Agent UML (Bauer, 2001), Message UML (Caire, 2001), FIPA standards (FIPA, 1997) etc.]
- Data classification and clustering algorithms: Evaluation of different algorithms specified for data classification and clustering will be reviewed and evaluated [i.e. Kohonen maps (Kohonen, 1996), K-means clustering (Tarassenko, 1998) etc.]
- AI based data interpretation techniques: Different data interpretation methodologies using AI techniques will be considered and evaluated for the integration of the platform.
- Implementation of intelligent condition monitoring platform: Following the analysis and design phase within the first year of the project the implementation will take place using standard programming toolkits and languages in order for the platform to be operating system independent.
- All main algorithms and techniques for human problem solving during the monitoring procedure will be investigated and appropriate upgrades will be done to the software platform.
- Specification of application areas will take place straight after the implementation phase for case studies applications. The areas that will be considered include: bioscience, agriculture, health care, biomedical engineering and food business.
- The application and evaluation of intelligent monitoring platform within different applications will take place, which might indicate certain upgrades to the existing platform and extension with other systems specific to the application domains.
- Development of graphical user interface for software platform: Reflecting upon the different applications of the platform and evaluating the user's feedback the graphical user interface will be implemented.

The software platform at the end of this project will constitute a self-contained application independent product for intelligent monitoring. Due to the flexible, autonomous, independent, modular agent-oriented architecture of the platform, we expect integration of existing. The key areas of research orientation include the following themes, which will be addressed in detail within the final proposal:

- Standardization of computer-aided agent-based monitoring platform
- Agent-oriented software engineering for application independent software development
- Application within certain areas of bio-informatics and evaluation of the software
- The use of databases for knowledge extraction and automatic feedback to the software platform

- Evaluation of Intelligent Agents' communication functionality to support integration of legacy systems.

The benefits of this project will be three-fold:

- Economic: The agent-based platform with the integrated tools for data classification and clustering, along with the embedded AI techniques and automated modelling and simulation will enable to minimize capital investment and operating costs of certain projects within biotechnology. This will be achieved by reducing process steps, predicting specific problems and conditions under which the problems can occur and increasing equipment utilization through better scheduling and understanding of the problem domain.
- Scientific: The tools within the intelligent platform will enable engineers and scientists to model on the computer integrated environment the procedures for monitoring processes and allow a comprehensive knowledge archive to be constructed specifying operational goals and strategies; problem solving techniques; models of expert domain understanding; case studies of previous experience, etc. Along with the knowledge archive for certain application domain, the knowledge extraction, knowledge discovery (use of existing databases to identify knowledge in any form: rules, artificial networks etc. about a particular process) is of high importance.
- Educational development: Apart from the fact that knowledge will be archived, emphasis should be given to the scientific merit of the knowledge reuse for experts' training within certain areas. New employees within a company will be educated based on the knowledge archived in the system, and the different models and simulations that have been created during operations for training and reference purposes.

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