USING PROMETHEUS METHODOLOGY FOR MULTI-AGENT SYSTEM DEVELOPMENT

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Multi-agent systems (MAS) represent an adequate approach for solving complex problem in various domains such as industry, education, medicine, business, networking and mobile technologies. Due to their capacities, agents form "self-organized systems" and tend to find the best solution for their problems "without intervention".

In this paper the author presents an example of MAS designed for the diagnosis of a three-phase gas-oil separator from a separation plant. The methodology used for developing GOSP-MAS is Prometheus, a well-known agent-oriented methodology. The author follows the three main steps in MAS developing, namely domain analysis, architectural design and detailed design. This article highlights the domain analysis phase.

Keywords: multi-agent systems, agent-oriented methodology, gas-oil separator

1. Introduction

Diagnosis and monitoring are important functions within the operation, control and management of industrial systems. A significant number of research activities have led to the development of intelligent system techniques that support these functions. In the real world, the experience has shown that often more than one intelligent system technique is required to perform the diagnostic or monitoring function.

Developing multi-agent systems for technical diagnosis in oil industry represents an interesting research topic, as evidenced by the large number of papers in the field [1][2].

This article is a result of the author's research work during doctoral internship and focuses on the modelling process of a multi-agent system applied in industrial area. The main concern of the author was to identify the architecture of the multi-agent system, starting from the gas-oil separation plant requirements and constraints. The domain analysis represents the first step in a multi-agent system methodology where the inputs, the outputs and the relation between them are identified.

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The paper is organized as follows: Section 2 presents several examples of multi-agent systems applied in oil filed and a comparison with the multi-agent system proposed in this article. Section 3 includes an overview of the Prometheus methodology used to build the multi-agent system. The first phase of GOSP-MAS development (domain analysis) proposed by the author is given in Section 4. Final remarks and plans for future research are indicated in Section 5.

2. Related work

A multi-agent system consists in more intelligent agents capable to work together in order to accomplish the initial proposed goal. The main characteristics of such agents are: autonomy, adaptability, sociability, reactivity and learning. Within the system, agents exchange messages, negotiate and cooperate in order to reach the objective, according to their roles.

An example of MAS application in oil field is presented in [1]. The authors work with a methodology for the design of an intelligent supervisory system that combines the principles of fuzzy logic, the Internal Model Control (IMC) architecture and the paradigm of MAS. In this research work, two kinds of complex petroleum industrial processes are described and analysed from an agent-oriented approach, namely the gas-oil separation process and the oil heating process.

There are M classes of processes identified as P_1, P_2, ..., P_M, where M is the number of processes classes and N is the amount of processes for each M class. Therefore, the authors considered N as the supervisor local agent for each class of processes. In this example, every process is governed by its local supervisor and, at the same time, it is connected to the global supervisor.

Similarly, the GOSP-MAS system architecture contains a supervisor agent, i.e. the Diagnosis Agent, responsible with the entire system monitoring. Additionally, this agent will notify the faults/errors occurring during the separation process. The other local agents (Operator Agent, Process Agent, FA Agent, FP Agent, FG Agent, SC1 Agent and SC2 Agent) have well-established tasks within the multi-agent system. The description of the above mentioned agents can be found in the architectural design phase of the Prometheus methodology.

In paper [2] a reference model for fault management in industrial processes is proposed. It is based on a generic framework using multi-agent systems for distributed control systems. The author uses a particular methodology for the conception, analysis and design of the agent systems. As a result of the research work, a set of models describing the general characteristics of the agents, specific tasks, communications and coordination within the MAS is obtained [2].

A process plant of a petroleum offshore unit represents a complex artifact consisting of independent equipment which interact and work together in order to get petroleum from subsea reservoirs, then treat it and export gas and oil to land refineries. This environment is appropriate to develop multi-agent systems for the management of the industrial processes. Each piece of equipment behaves and reacts to accomplish its own goal, such as agents that communicate and collaborate within the MAS. Inspired by the distributed and encapsulated aspect of the process plant artifact physical model, the authors of research paper [4] proposed a multi-agent-based alarm management system to synthesize the process plant situation during emergency situations. Each designed agent represents an item of equipment that "understands" their expected and unexpected behaviour within the process plant.

After the study of state-of-the-art experiments regarding intelligent agents' application in industry, the author of the present article proposes a multi-agent system design for the diagnosis of a three phase gas-oil separator from a separation plant (GOSP-MAS). The agent-oriented methodology to build the MAS is Prometheus [8] and consists of three steps, namely domain analysis, architectural design and detailed design (i.e. building the internal structure of each agent in the proposed system and specify how they fulfill their tasks by defining the necessary messages and protocols). The article focuses on the domain analysis phase.

3. A short description of the Prometheus methodology

As presented in literature, [8][7][3][5], the Prometheus methodology represents a detailed process for specifying, designing, implementing and testing/debugging agent-oriented software systems. It works with concepts such as: goals, belief, plans and events.

The main characteristics of this agent-oriented methodology are as follows:

- ✓ Each agent has one or several goals, interacts with other agents, communicates and negotiates according to a plan and accomplishes its tasks throughout the events.
- ✓ Prometheus provides explicit modelling of goals which is needed to support proactive agent development.
- ✓ This methodology ensures flexibility and robustness of the messages (or events) by enabling them to be handled on several plans.
- ✓ Agents are situated in an environment, and therefore, it is important to define the interface between the agent and its environment in order to facilitate communication.

- ✓ In agent-oriented programming there are two types of components, namely passive components such as data and belief, and active components, such as agents and plans.

The Prometheus methodology consists of three phases: the domain analysis (system specification), the architectural design and the detailed design [8]. The system specification phase consists in describing the overall goals and basic functionality, including the illustration of the systems' operations with the use of case scenario schemes. The phase is also intended to specify inputs (for example sensor readings within an industrial plant) and outputs (actions), namely the interface between the system and its environment. The second phase (the architectural design phase) decides about the number and the types of agents which will further describe the physical analysed system (i.e. three phase gas-oil separator). In the same time the developer must decide how they shall interact based on the previous phase. The final phase (the detailed design phase) takes each agent individually and describes its internal behaviour in order to complete its goals within the overall system.

4. GOSP-MAS: system specification phase

This section of the paper presents the analysis domain (system specification) phase for GOSP-MAS development using Prometheus methodology. The function of an oil production facility is first to separate the oil well stream into three phases: oil, gas and water. Second, these components are processed into marketable products or disposed of in an environmentally acceptable manner. The physical devices responsible with these functions are known as separators, where gas is flashed from the liquids and "free water" is separated from oil [9]. Separators are classified as two-phase ones, if they separate gas from the total liquid stream. If the resulted components of the separation process are gas, oil and water (the separators also separate the liquid stream into crude oil and water components), the separators are known as three-phase separators. After the main process of separation, the gas that is evacuated from the separator is compressed and treated for sale. Modelling such facilities has become very crucial for the controller design, fault detection and isolation, process optimization, and dynamic simulation [9]. Applying agent-oriented approach to solve the complex problems in oil field is a continuous concern of researchers.

The author proposes a multi-agent system called GOSP-MAS, able to manage the entire separation process, by offering diagnosis, control and management functions for a three-phase separator from a separation plant.

The agents of GOSP-MAS must have the following capabilities:

- ✓ to adjust the fluid temperature in order to ensure its optimal separation into three phases: gas, oil and water;

- ✓ to monitor and control the pressure and the level of the three components of the separation process;
- ✓ to provide and communicate the necessary data for the detection of critical situations and for the generation of diagnosis reports.

GOSP-MAS will be capable to communicate with human operators from the control room. Simultaneously, the operator should be notified when critical situations appear and the multi-agent system should react and respond correctly to the instructions from the human operator. The environment is common for all agents and is represented by the separator plant. The following characteristics were identified regarding the agents' environment:

- ✓ inaccessible – the agents do not have access to the complete state of the environment.
- ✓ non-determinist – it is permanently influenced by the actions of the other agents;
- ✓ non-episodic;
- ✓ dynamic – constantly changing during the separation process;
- ✓ continuous – the indicators used by the system take values in a continuous range of values.

According to Prometheus methodology, system specification phase consists in defining: the system goals and sub-goals, the set of scenarios developed based on system goals, the interface of the system described by actions and percept, and the necessary roles.

5. Goals specification

The section presents an extract of system goals and sub-goals and the most important scenarios and roles of the system agents. After analysing the three-phase separator functions, there were identified the following goals for GOSP-MAS:

- ✓ [Goal 1] Mixture separation;
- ✓ [Goal 2] Mixture heating for each heat exchanger;
- ✓ [Goal 3] Changing the temperature set point;
- ✓ [Goal 4] Gas pressure control;
- ✓ [Goal 5] Changing the pressure set point;
- ✓ [Goal 6] Control of the oil level in the separator;
- ✓ [Goal 7] Changing the oil level set point;
- ✓ [Goal 8] Control of the water level in the separator;
- ✓ [Goal 9] Changing the water level set point;
- ✓ [Goal 10] Handling critical situations.

A description for each goal is necessary to better decompose these goals in the next step of the system specification phase. The author exemplifies with five goals and their specific description (table 1).

Table 1

Goals specification

Number	Goal	Description
[Goal 1]	Mixture separation	A condition for the mixture separation into gas, oil and water phase is the flow temperature input which must range between 35÷40 ^{0}C
[Goal 2]	Mixture heating for each heat exchanger	The temperature sensors, corresponding to the two heat exchangers, measure the temperature at their inlet and outlet. If the mixture temperature at the outlet of heat exchanger does not correspond to the set point, the corresponding control valves are operated in order to adjust the temperature.
[Goal 3]	Changing the temperature set point	Human operator from the control room has the authority to modify the set point of the mixture temperature. The actions of the human operator should be prioritized in relation to the multi-agent system.
[Goal 4]	Gas pressure control	In order to control gas pressure, the current pressure value (i.e. the measured pressure), the set point and the maximum/minimum limit must be available. An overview of the current conditions in the separator is obtained by means of sensor data analysis. When the measured value is higher than the set point, a control pressure is needed and the corresponding control valve is acted.
[Goal 5]	Handling critical situations	The agent system should be able to detect and handle critical situations occurring in the three-phase separator function. The main responsibilities of the agent system in such cases are to generate an appropriate alarm and to notify the human operator from the control room. The operator analyzes the diagnosis report and can adjust the parameters manually.

6. Goals refinement

The process of capturing the goals of the multi-agent system begins by capturing an initial set of goals from the high-level system description. Furthermore, these initial goals are depicted into a more complete set of goals by considering each goal and asking how that goal could be achieved [5]. As a result, the additional sub-goals are identified. For the [Goal 1], [Goal 2], [Goal 3], [Goal 4] and [Goal 10] described above, the following sub-goals were defined:

✓ [Goal 1] Mixture separation

- [Sub-goal 1.1] Measuring the temperature inside the separator
- [Sub-goal 1.2] Monitoring and detecting critical situations

✓ [Goal 2] Heating mixture for each heat exchanger
- [Sub-goal 2.1] Measuring the temperature inlet of the heat exchanger
- [Sub-goal 2.2] Measuring the temperature outlet of the heat exchanger
- [Sub-goal 2.3] Calculating the difference between the inlet temperature and the outlet temperature
- [Sub-goal 2.4] Acting the control valve
- [Sub-goal 2.5] Monitoring and detecting critical situations

✓ [Goal 3] Changing the temperature set point
- [Sub-goal 3.1] Establishing the temperature set point
- [Sub-goal 3.2] Accepting changes

✓ [Goal 4] Gas pressure control
- [Sub-goal 4.1] Measuring the gas pressure
- [Sub-goal 4.2] Calculating the difference of pressure
- [Sub-goal 4.3] Opening the control valve
- [Sub-goal 4.4] Monitoring and detecting critical situations
- [Sub-goal 4.5] Calculating the gas flow

✓ [Goal 10] Handling critical situation
- [Sub-goal 10.1] Monitoring and detecting critical situations
- [Sub-goal 10.2] Generating the diagnosis report
- [Sub-goal 10.3] Notifying the human operator

7. Scenarios development

The third aspect of the system specification is the case scenarios that can be defined as: “a detailed description of one particular example sequence of events associated with achieving a particular goal, or with responding to a particular event” [8].

Scenarios are described by using three elements: a name, description, and a triggering event and consist of a sequence of steps. For each step there are defined the functionality that performs that step, the name of the step, its type (one of ACTION, PERCEPT, GOAL, SCENARIO or OTHER) and, optionally, the information used and produced by that step. The author enumerates, as examples, the following scenarios:

✓ [Scenario 1] Mixture separation in the three phases
Trigger: The mixture does not have the optimum temperature for the separation process
The fluid temperature is measured at the inlet of the separator.
PERCEPT: The temperature sensor values

GOAL: Mixture separation
GOAL: Measuring the temperature inside the separator
SCENARIO: [Scenario 2]
OR
GOAL: Monitoring and detecting critical situations
SCENARIO: [Scenario 10]

- ✓ [Scenario 2] Mixture heating for each heat exchanger
Trigger: There is a request for fluid temperature control
The fluid temperature is measured at the inlet/outlet of the heat exchangers. If the values are outside the range of the set point values, the control process is initiated and the control valve installed on the pipe coming from the heater is acted. During the control process, any possible critical situation will be detected.
GOAL: Measuring the inlet temperature at the heat exchanger
GOAL: Measuring the outlet temperature at the heat exchanger
GOAL: Calculating the difference between the inlet/outlet temperatures
SCENARIO: [Scenario 3]
OR
GOAL: Monitoring and detecting critical situations
SCENARIO: [Scenario 10]
- ✓ [Scenario 3] Acting the control valve
Trigger: There is a request for opening/closing the control valve
After calculating the difference between the measured value and the set point, the system changes the control valve state.
ACTION: Modifying the control valve state (close/open)
- ✓ [Scenario 10] Handling critical situation
Trigger: Critical situation occurs and is identified
When a critical situation is identified, the system generates a diagnosis report with all the alarms and informs the human operator from the control room about it.
PERCEPT: sensor values (level/temperature/pressure sensors)
GOAL: Monitoring and detecting critical situations
GOAL: Generating the diagnosis report with alarms
ACTION: Display diagnosis report
GOAL: Notify the human operator

8. Roles development

The system functionality is described by its roles, characterized, according to Prometheus methodology, by the following aspects: trigger, description, percept, goals and/or actions connected to them. Some of the system roles are presented below:

- ✓ [ROLE 01] Separator monitoring
  Trigger: New values registered by temperature sensors from the separator.
  Description: Responsible with mixture temperature monitoring at the inlet of the separator in order to initiate the separation process.
  Goals: Mixture separation, measuring the temperature inside the separator.
  Percept: Temperature sensor value at the inlet of the separator.
- ✓ [ROLE 05] Water level monitoring
  Trigger: New values registered by level sensors.
  Description: Responsible with water level monitoring within the separator and with calculating water flow.
  Goals: Measuring water level and calculating water flow.
  Percept: Level sensors values and flow indicator value.
- ✓ [ROLE 10] Critical situation detection
  Trigger: Critical situation has occurred.
  Description: Responsible for detecting critical situations.
  Goals: Monitoring and detecting critical situations
  Percept: Temperature sensor values, pressure sensor values, level sensors values.

The elements defined during the system specification phase will represent the basis for the architectural design phase when the system agents are developed and the interaction between them are established.

9. Conclusions

The paper presents an example of multi-agent system applied in oil industry which was developed with the Prometheus methodology. The proposed system is GOSP-MAS, a solution for monitoring, controlling and diagnosing a three-phase separator from a gas-oil separation plant. According to Prometheus methodology, a multi-agent system can be developed in three main steps: system specification, architectural design and detailed design. In this article, the author describes only the first phase of this agent-oriented methodology.

After a careful analysis of the physical system (i.e. the three-phase separator), the author has developed the system goals, which he has also refined, and a hierarchical structure of the resulting sub-goals. The process of refining and further grouping of goals implies an initial set of system functionalities. Future research of the author in the field of scenarios and specification development may bring into light additional ones.

System specification is an iterative process, starting with identification of goals, and continuing with goal refinement, then moving/ choosing between scenarios, goals and functionalities, as well as identifying actions, percept and data.

Future research work will focus on the next phases of GOSP-MAS development, namely the architectural design and the detailed design.

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