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An agent-based model for water quality control

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Abstract

Intelligent agents approach represents one of the promising technologies for building complex software systems. The agent-based solution could be applied with success in the environmental management. Monitoring the quality of a drinking water supply must be effective and efficient since water is essential to human health. A community of agents is assigned to the task of monitoring a network of sensors in order to assess water quality in a distribution system, and to fire alarms in emergency situations. The architecture of the developed system and typical agent interactions are presented. An example of an application is described. The proposed agent-based model will have real-time decision-making capabilities in addition to routine decision support tasks.

Keywords

Distributed Artificial Intelligence, Water Quality Monitoring, Multi-Agent Systems, Intelligent Environmental Monitoring,

1. Introduction

Intelligent agents (also known in literature simply as agents) are problem-solving software entities, which possess humanlike intelligent properties such as: autonomy, reasoning, sociability, learning ability, etc [1,2]. Agents differ from objects (as in object oriented programming) in their degree of autonomy. Objects have control over their methods, but they do not exhibit control over their own behavior. Intelligent agents are autonomous entities capable of exercising choices over their actions and interactions [3]. Agents are often deployed in an environment where they can interact with other agents (through cooperation and negotiation skills) or with the environment, the final goal being to accomplish special tasks that cannot be achieved by conventional software. Such environments are known as multi-agent systems. We propose the application of the agent-based software to water quality monitoring for regulatory compliance. Multi-agent systems have several features that makes them suitable for the task stated above: speed-up and efficiency (agent can act asynchronous and in parallel, resulting in an overall increased speed-up), robustness and reliability (failure of one component does not make the entire system inoperable), scalability and flexibility (the system can be adapted to an increased problem size by easily adding agents), cost, development (due to computer standardization individual agents can be developed by different specialists) and reusability (possibility of reuse and reconfigure agents in different application scenarios). We begin by briefly pointing to the European norms in the field of water management policy and to water quality legislation in Romania. The focus is on “water intended for human consumption”. A few EU programmes supporting the implementation of these measures in Romania are described (section 2). Section 3 is a brief introduction to the concept of a multi-agent model applied to real time water quality monitoring (also known as “Early Warning Systems”). Section 4 details the implementation of the described early warning system in the context of water management in the region Prahova. Section 5 concludes the application presented in this paper.

2. Water quality control

Romania has made significant progress in implementing the directive 2000/60/EC of the European Parliament and of the Council, directive which establishes a framework for Community action in the field of water policy [4]. To insure an efficient pollution control of European water bodies, the directive 2000/60/EC proposes a common objective for all states that are committed to implementing it: the achievement of “good ecological and chemical quality” of water sources by 2015. It is noteworthy to mention two 2005-2007 PHARE projects [5] (summing up 10 million Euro) aimed at the implementation of the directive 2000/60/EC in Romania. One project was designed for the endowment of ANAR (National Administration Romanian Waters) laboratories with high-tech instrumentation for the monitoring of chemical and biological parameters specified by the European legislation. The second project was directed at providing technical assistance for the establishment of a statewide informational system and of a national database in the field of water management. The paragraph (37) of article (2) of the directive 2000/60/EC states: “Water intended for human consumption has the same meaning as under Directive 80/778/EEC, as amended by Directive 98/83/EC”. One of the requirements of Directive 98/83/EC[6] is that “regular monitoring of the quality of water intended for human consumption is carried out, in order to check that the water available to consumers meets the quality specifications”. The norm 98/83/EC identifies two types of monitoring programmes and the frequencies at which these tasks need to take place (see Annexes I and II of 98/83/EC). Directive 98/83/EC specifies that additional monitoring may be appropriate on a case-by-case basis. For instance, in the case of microbiological indicators, the degree of confidence that 98% of the water supply system is free of thermotolerant coliforms is 20% if the system is monitored on a monthly basis, and 98% if the system is monitored four times/week [8]. Continuous monitoring of water will improve the control of water quality on a daily basis, will ensure effective disinfection is maintained and will prevent the outbreaks of waterborne diseases.

3. The Agent Based Model

To develop our MAS we used specific techniques and tools. For the early requirements analysis phase we used the TROPOS methodology[9], and in particular, the design tool TAOM4E (Eclipse platform plug-in)[10].

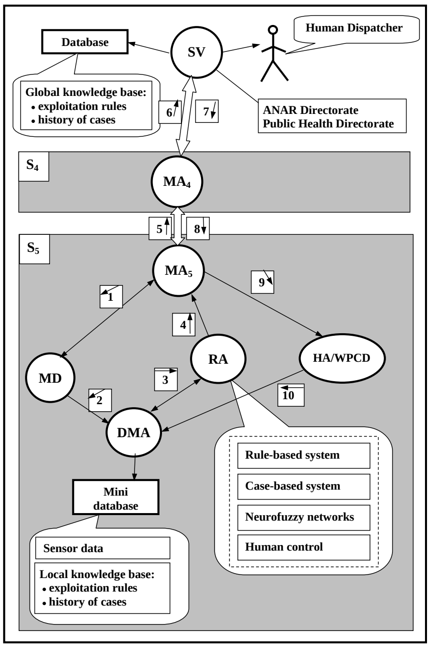

Figure 1. Multi-agent system architecture

For the Analysis and Design Phase we used GAIA methodology[11]. Protocols are modeled using the Agent UML sequence diagrams[12]. The inter-agent communication within the MAS is to be realized according to FIPA specifications, and the system is to be implemented in JADE[13]. A more detailed description of the analysis and design for this system is presented elsewhere[14]. In this paper, for conciseness, we describe the architecture of the system and we present a representative interaction diagrams specific to our agent-based model. Fig. 1 is a schematic diagram showing three monitoring stations: a supervising station (SV) and two regular stations (S4 and S5). The activity of each regular station is controlled by several agents and a measuring device (MD). The measuring device corresponds to real life automated online analyzers. The agents of the model are: the Monitoring Agent (MA), the Water Pollution Controlling Device or a graphical user interface controlled by a human operator (WPCD/HA), the Database Management Agent (DMA) and the Reasoning Agent (RA) which is responsible for implementing high level decision support and online decision making in emergency situations. We identify two levels of organization in the environment: the sensor level and the coordination level. The sensor level environment is confined to a small area and data flow mainly consists of sensor data concerning water quality. The coordination level is localized to a larger geographical region in which the supervising station, ANAR, PHU (Public Health Unit) and monitoring agents can communicate through high speed networks connections.

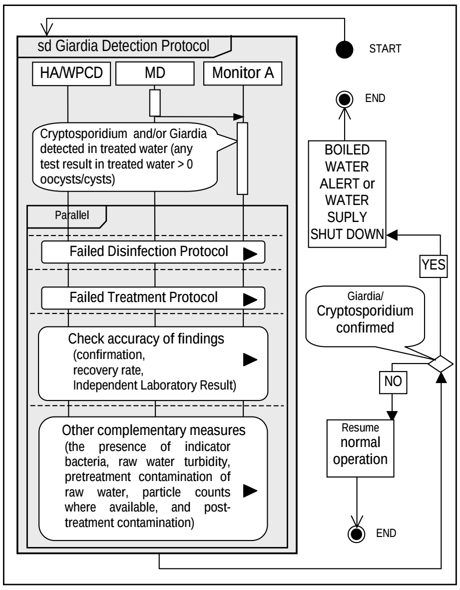

Figure 2. Giardia or Cryptosporidium protocol implemented at the sensor level

At the coordination level, data flow consists of “system status” reports, explicit warning/alarms events, and logistic coordination of stations and substations, as for instance in the case of localizing a point source of pollution affecting a larger community. As previously mentioned, continuous monitoring may prevent outbreaks of waterborne diseases by identifying a possible microbiological contamination at one or more of the sites. Action on detecting

Cryptosporidium oocyst has to follow the guidelines described in the Response Protocol Following Failure in Water Treatment or Detection of Giardia or Cryptosporidium. Figures 2 describe this protocol in AUML notation, as it will be implemented in our MAS system. For other protocols following total and E. coli bacteria detection or in case one or more physical or chemical indicators exceed recommended values, see [15].

4. Example of application

The implemented multi-agent system will monitor the local water distribution system in the region Prahova. We identified the principal surface sources of drinking water in Prahova region, namely the dams at Paltinu and Maneciu, the second one serving a population of about 21.670 people. In designing our system we follow the guidelines provided in [16]. In order to develop the plan for the interpretation, use and reporting of monitoring results we established contacts with: water utility companies(ESZ and SGA Prahova, Jovila si APANOVA Prahova, Hidro Prahova), local and state health departments, emergency response units(Dispeceratul pentru situatii de urgenta Prahova), law enforcement agencies and political leadership (prefectura Prahova, primaria Ploiesti). We are building the hydraulic model of the distribution network using the EPANET software from EPA (Environmental Protection Agency USA) and we identify access points, flow and demand patterns and pressure zones using the information from the water authorities. We plan to implement the monitoring following a two-stage approach. In a first stage, the real-time screening of contaminants which in case of a positive response will trigger a second stage action. The second stage consists of confirmatory analysis, follow-up action (repeat probes and lab tests) and response action: modification of the water system (closing valves, addition of disinfectants, etc), additional data gathering and monitoring, follow-on surveillance and epidemiological studies. The monitoring technology we choose is a network of state-of-the-art, UV-VIS spectrometers. The spectrometer has been extensively tested against conventional testfilters [17]. It can measure: turbidity, organic carbon (TOC, DOC), nitrate, benzene, pH, electric conductivity, ORP, NH4, DO, redox but also pressure, temperature and flow. It can be installed in various points of the distribution network, along water treatment and also at the consumer use(tap), and the network of sensors can be coordinated over the internet. Data processing (management, interpretation and reduction of data), optimal location of sensors, fate and transport of pathogens and chemicals, alarm levels and resposes are all important factors which need to be further explored in optimizing the described Early Warning System.

5. Conclusions and future work

Multi-agent systems can provide faster and more effective methods of resource allocation in complex environments, such as the management of utility networks, than any human-centered approach. This paper describes an early stage of development of a multi agent system for water pollution monitoring and control. The multi-agent system can be used for real-time monitoring of water quality for regulatory compliance with national and European legislation regarding national drinking water quality. This is a first step in the implementation of a multi-agent system which takes itself decisions, not only provides advice to human decision-makers.

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