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A Multi-Agent System for Power Plants Air Pollution Monitoring

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Abstract: Intelligent real time power plants air pollution monitoring is one of the current challenges for the research communities from the power industry, control engineering, electronics, environmental engineering and artificial intelligence fields. The use of distributed artificial intelligence approaches can provide efficient solutions to an intelligent monitoring. The paper presents a multi-agent system for monitoring urban air pollution due to power plants operation. A case study is discussed for the Ploieşti town area, where several refineries are located around it, some of them being thermal power providers. The multi-agent system was tested as a simulation.

Keywords: Air pollution, Environmental monitoring, Artificial intelligence, Multi-agent system, Distributed simulation

1. INTRODUCTION

Air pollution monitoring and control became one of the main environmental problems of most industrial sectors that need efficient and long-term solutions in order to increase the quality of life. An important source of harmful pollutants released in the atmosphere is the power industry. Therefore, there is a special concern on reducing the emissions from power plants. Moreover, the more rigorous national and international regulations regarding environmental pollution determined the power plants management to include in their strategic plans concrete solutions to the problems regarding the air, water and soil pollution. In this context, the development of intelligent real time air pollution monitoring networks provide a start point for the implementation of concrete air pollution control decisions based on knowledge. Artificial intelligence can offer a set of techniques (e.g. computational intelligence), and technologies (e.g. intelligent agents) for the implementation of an intelligent air pollution monitoring network. In this paper, it is proposed the solution of a multi-agent system for power plants air pollution monitoring in the urban region of the Ploieşti city, where four refineries are located in its vicinity.

2. POWER PLANT AIR POLLUTION

The main air pollutants emitted by power plants are SO_2, NOx, particulate matters (PM), mercury, and other metallic toxics. Also, power plants emissions have an important influence on ozone. In particular, the air pollutants from petroleum refineries are SO_2, NO_X, CO_2, phenol, NH_3, PM. Each air pollutant has specific maximum admissible limits of their concentrations, established by air quality standards. The influence of power plants air pollution on human health and ecosystems is extremely important.

Several research works reported worldwide in the last years present studies of the power plants impact on the environment pollution. For example, two Romanian studies have been published recently. In Pavelescu et al. (2005) it is discussed the impact of nuclear power plants on the environment pollution, and in Popescu et al. (2011) it is presented a case study of on line air quality monitoring in the Romanian city of Timişoara that included a power plant area. The air pollutants that were monitored are NOx, SO_2, CO, O_3 and VOCs. The experiments were done in some key areas of the city (e.g. center area – the Botanic Park, industrial area – Electromotor, power plant – Cet Sud), and showed that the national and international air quality regulations are accomplished with some exceptions for NOx concentrations near the city roads.

At the international level, we have selected two studies reported lately. Wile and Marron (2006) present a study of the economic impact of the new environmental rules on electric power systems proposed in March 2005: the Clean Air Interstate Rule – CAIR (that control SO_2 and NOx emissions), and the Clean Air Mercury Rule – CAMR (that control mercury emissions). In this context, the authors made also an analysis of the influence of controlling carbon at federal level on the SO_2, NOx, mercury, and carbon emissions. Yuval and Broday (2009) present a case study of the long term impact on the regional ambient air (in the Mediterranean coastal region from Israel) from three power plants with different power outputs, fuel types and stack heights. The air pollutants that were analyzed are SO_2, NOx, O_3 and $PM_{2.5}$. The authors demonstrated the impact of various industrial sources on the ambient SO_2 in the region that was considered for the case study. Also, the analysis of NO, NO_2 and O_3 concentrations suggested that the highest NO_2

concentrations are probably due to recirculated NOx emitted by traffic in densely populated regions.

As a conclusion we can say that all these studies emphasized the importance of air pollution monitoring in order to assess the environmental impact of power plants air pollution.

3. INTELLIGENT POWER PLANT AIR POLLUTION MONITORING

Intelligent monitoring can be viewed as monitoring based on artificial intelligence techniques, and intelligent sensors, and devices. Various intelligent power plant air pollution monitoring systems were presented in the literature. A brief review of selected research done in this domain is presented as follows, grouped by the used method.

3.1 *Intelligent sensors and devices*

Lee et al. (2004) presents the research work done for the development of an intelligent monitoring system that use distributed optical sensors for real time monitoring of high temperatures in a boiler furnace in power plants. One of the system's goals is to assess and control the NOx pollutants at source. Sujatha et al. (2011) tackle the problem of flue gas monitoring in thermal power plants, and propose the solution of using an intelligent soft sensor for the extraction of information regarding the flue gas emissions that have an important impact on air pollution and global warming.

3.2 *Multi-agent systems*

A very interesting agent-based solution is given in an early research work of Seco et al. (1998). The authors proposed the use of a small society of flying robotic agents (i.e. helicopter models) that collaborate for air pollution monitoring and analysis of a pollutant cloud around the chimney of a power plant. The solution was tested by simulation. In Zhou et al. (2007) it is made a review of the agent-based simulation tools for electricity markets. Also, the authors propose an agent-based simulation framework for electricity markets in order to facilitate the development of future models of electricity markets. McArthur and Davidson (2004) focused on the use of multi-agent systems for diagnostic and condition monitoring applications in the case of power plants (e.g. electrical power plants). Amato et al. (2005) introduced the use of Web Agents in an environmental monitoring agent-based system as information providers for the other agents that make different tasks (e.g. forecasting, brokering etc). More specifically, the Web Agents acquire different images from the Web for a specific area that is monitored, and extract from these images the information regarding the meteo-climatic conditions that will be sent to the knowledge base of the other agents. Hussain et al. (2006) presents the architecture and design of agent-based sensor networks for petroleum offshore monitoring, pointing out some challenges in monitoring the reservoir, wellbore and wellhead. Also, the software design of a web-based continuous monitoring application is discussed. Chappin et al. (2007) proposed an agent based model for the system of electricity production systems in order to explore the impact of CO_2 emission-trading. The model emulates the long-term evolution of the European electricity production system of systems as a series of investment decisions made by independent agents. The experimental results obtained by simulation provide recommendations for the European CO_2-policy.

3.*3 Wireless agent-based sensor networks*

In the last years, the use of multi-agent systems in wireless sensor networks was intensively studied, this being still one of the nowadays research challenges on developing efficient environmental monitoring systems. A recent solution is given in Saleh et al. (2012), the hierarchical and heterogeneous mobile agent-based wireless sensor networks. The authors introduced a novel architecture for organizing wireless sensor networks in a hierarchy blending the mobile agent technology over the internet and sensor devices. Potential applications of this solution include environmental monitoring in power plants areas.

3.4 *Computational intelligence techniques*

In Ćirić et al. (2012) it is presented the estimation of air quality by using three computational intelligence techniques based on artificial neural networks (feed forward neural network – FFNN, recurrent neural network – NARX, hybrid neuro-fuzzy estimator - ANFIS) for the estimation of CO_2 emissions in the city of Niš, Serbia.

From the brief study presented in this section, we can conclude that there are several intelligent power plants air pollution monitoring systems that apply either pure technical solutions (i.e. intelligent sensors and devices), or software artificial intelligence based solutions, or a mixture of them. However, there are still many challenges of implementing efficient solutions for power plant air pollution monitoring.

In the next section it is presented a multi-agent system developed for the air pollution monitoring in the urban region of the Ploiesti city, where four petroleum refineries are located. The system was tested as a simulation.

4. MULTI-AGENT SYSTEM FOR AIR POLLUTION MONITORING

The PPAPMS System (Power Plant Air Pollution Monitoring System) proposed in this paper is a multi-agent system built for the monitoring and analysis of the main air pollutants (carbon monoxide- CO, nitrogen monoxide- NO, nitrogen dioxide- NO_2, sulphure dioxide- SO_2, and particulate matter - PM_{10}) evolution in three key places in Ploieşti, near major local refining centers (one in the North area, two in the South part and one in the East side of Ploiesti). The data used in this simulation are provided by the Romanian Air Quality Monitoring Network and are available online: www.calitateaer.ro.

Four intelligent agents were designed for this system: *North_Agent, East_Agent, South_Agent*, and *EPA_Agent* (Environment Protection Agency Agent). Each agent represents one of the local measurement units of Ploieşti city, placed near major petroleum refineries, except the *EPA_Agent* which represents Environment Protection Agency that coordinates the activities of the other intelligent agents. The system architecture is presented in figure 1.

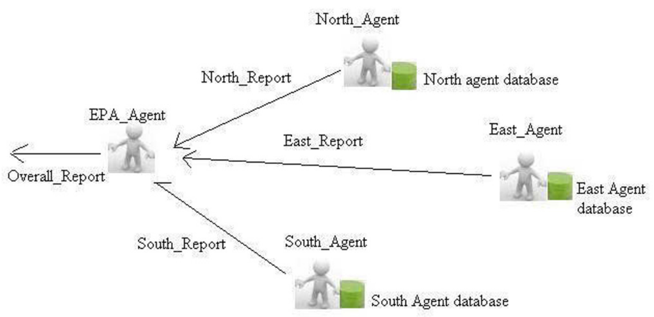

Fig. 1. The PPAPMS System architecture

At the request of the *EPA_Agent*, the agents extract the values recorded of the pollutants from the databases and a quality index for every air pollutant can be calculated. This index is determined based on multiple comparisons between the data supplied and the upper limit of the air pollutants' concentration, according to table 1.

Table 1. Mean concentration domains for each quality index

SO_2 ($\mu g/m^3$)	NO_2 ($\mu g/m^3$)	O^3 ($\mu g/m^3$)	CO (mg/m^3)	PM_{10} ($\mu g/m^3$)	Air Quality Index
0-49, (9)	0–49,(9)	0–39,(9)	0-2,(9)	0-9,(9)	1 (excellent)
50–74,(9)	50–99,(9)	40–79,(9)	3-4,(9)	10-19,(9)	2 (very good)
75–124, (9)	100–139, (9)	80– 119, (9)	5 - 6,(9)	20– 29,(9)	3 (good)
125–349, (9)	140– 199, (9)	120–179, (9)	7– 9,(9)	30– 49,(9)	4 (medium)
350–499, (9)	200– 399, (9)	180–239, (9)	10-14,(9)	50– 99,(9)	5 (bad)
>500	>400	>240	>15	>100	6 (very bad)

If there are local limit overruns an alert message is displayed. The local air quality indexes are sent to the *EPA_Agent* where the general air quality index is determined. Its value is the highest index of quality established for each pollutant.

4. 1 The data set

The data used in this study come from the Romanian Air Quality Monitoring Network which contains 117 fixed stations and 17 mobile ones. The databases contain the concentrations' values for the major pollutants recorded hourly between January 2011 and December 2011.

The data set for the *North_Agent* is provided by the PH3 measurement unit, for *East_Agent* it is used the PH6 recorded data, and for the *South_Agent* the data recorded by the PH5 station.

4. 2 Experimental results (running the application in simulation mode)

We have implemented the PPAPMS system in Zeus, a Java-based toolkit for intelligent agents. The system is designed for the monitoring and analysis of the air quality in three major industrial areas, where several refineries are located, some of them being thermal power providers. The air pollutants measured are carbon monoxide, nitrogen monoxide, nitrogen dioxide, sulphure dioxide, and particulate matter that were taken from public available databases.

In this simulation the user selects from the system interface the day and the hour desired for the analysis. The system interface is presented in figure 2.

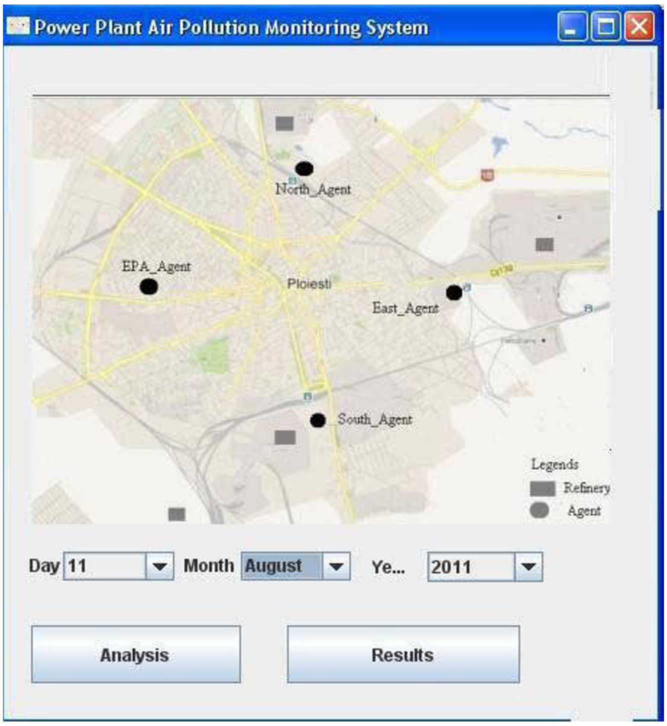

Fig. 2. The PPAPMS System interface

Furthermore these data are used in order to establish the system goal. To achieve this, the environmental agents work jointly with the supervisor agent, by sharing the same ontology and assisting each other when it is performed a general report on air quality. Thus, the *North_Agent*, *South_Agent*, and *East_Agent* extract from their data sets the concentrations' values recorded at their stations. A local analysis is made and the area air quality index is established.

These values are sent to the *EPA_Agent* in order to be calculated the general air quality index. The local possible warnings, as well as the overall report are being displayed on the system interface.

The collaboration between agents can be seen in figure 3, in the *Agents Society* with the messages exchanged between agents.

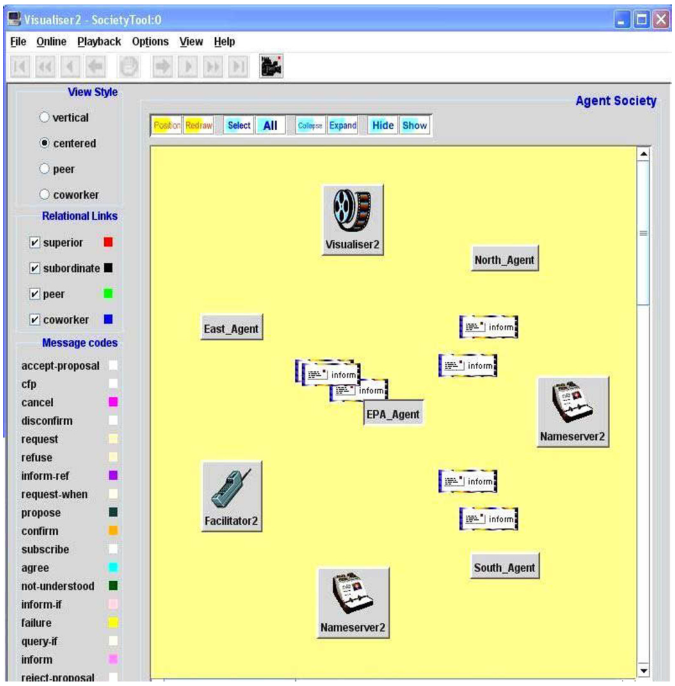

Fig. 3. The Agents Society of PPAPMS System in Zeus

In figure 4 is presented the *Report Tool*. Thus, the completed tasks are colored with white (*Generating_South_Report*, *Generating_North_Report*, and *Generating_East_Report*) and the green one is the task that is currently calculating the general air quality index in Ploieşti city (*Generating_Overall_Report*).

One case study was made for the 11th August 2011, 12.00 PM. After running the application the results are posted in figure 5. It can be noticed that in the South area the air quality index is 5 (bad), determined by the NO very high concentration: 247.3 µg/m^3. That influenced the overall air quality index value to 5 as well.

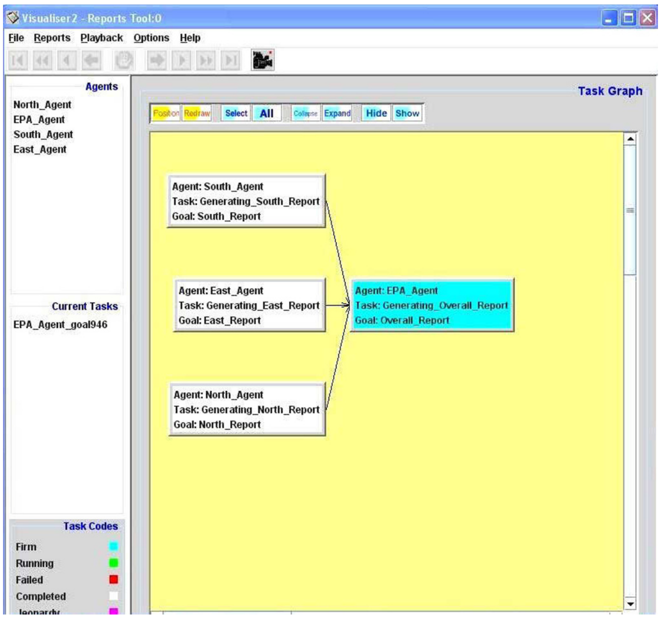

Fig. 4. Screenshot of the task graph obtained with the Visualiser agent during the of PPAPMS system run.

There can be generated a series of statistics related to the collaboration, inter-agent traffic volume, the distribution by type or by agent of the traffic volume.

In figure 6 it is presented the breakdown of the agents by type: each one of the agents *Nameserver, Facilitator* and *Visualizer* represents 14% of total number of system agents. The *Nameserver* and *Facilitator* agents are essential for the system because they are the ones who know the IP addresses and tasks that can be performed by each agent individually. The *Visualizer* agent is optional but very useful because it provides a possible interface between the user and the system. 57% of the agents represent the agents built for this specific application (*North_Agent, South_Agent, East_Agent,* and *EPA_Agent*).

A statistic of inter-agent traffic volume of the messages is presented in the figure 7. The maximum number of messages is 9, between the local agents and the *EPA_Agent*, followed by the communication between the agents and the Facilitator agent; each agent asks the Facilitator in order to find out what tasks can be performed by each agent individually.

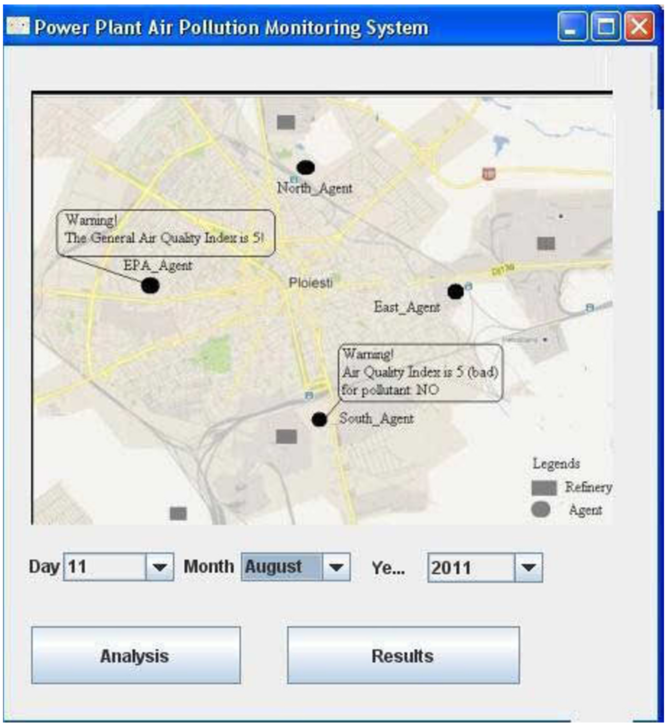

Fig. 5. The PPAPMS System results for the case study

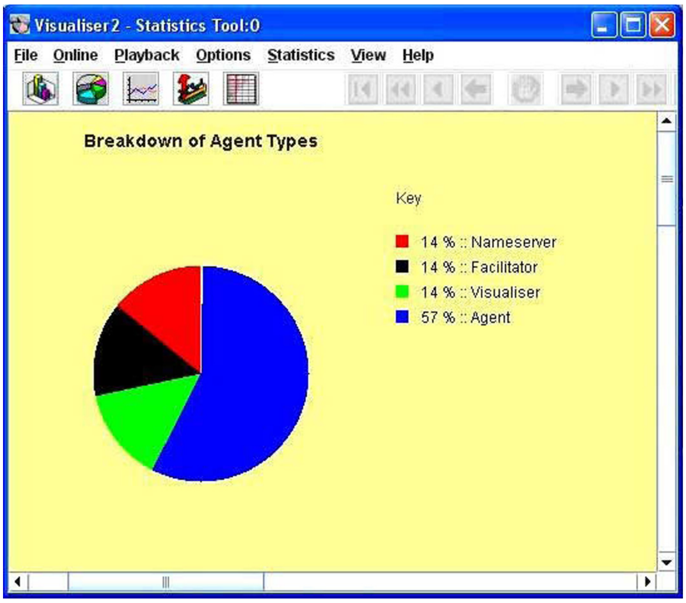

Fig. 6. The Statistics Tool of PPAPMS System in Zeus with the breakdown of agent types

	nameserver2	north_agent	east_agent	facilitator2	south_agent	epa_agent	visualiser2
nameserver2	0.00	0.00	0.00	1.00	0.00	0.00	0.00
north_agent	0.00	0.00	0.00	7.00	0.00	9.00	0.00
east_agent	0.00	0.00	0.00	7.00	0.00	9.00	0.00
facilitator2	1.00	1.00	1.00	0.00	1.00	1.00	0.00
south_agent	0.00	0.00	0.00	7.00	0.00	9.00	0.00
epa_agent	0.00	9.00	9.00	7.00	9.00	0.00	0.00
visualiser2	1.00	0.00	1.00	1.00	1.00	0.00	0.00

Fig. 7. The inter-agent traffic volume of PPAPMS System in Zeus

The collaboration among the agents is highlighted in figure 8 and figure 9, because the messages sent are 18% to *subscribe* (to ask the Facilitator which task is performed by which agent), 14% *call for propose* and 14% *propose* (the supervisor agent ask the other agents to send the information needed), 14% *accept- proposal* (with no negotiation the agents accept to fulfill the request) and 41% to *inform* (in order to achieve the general goal, the agents send the information requested).

Another statistic can be done for the traffic volume distributed by agent, as in figure 9. This statistic shows that the majority messages among agents provide the needed information in order to achieve the overall goal.

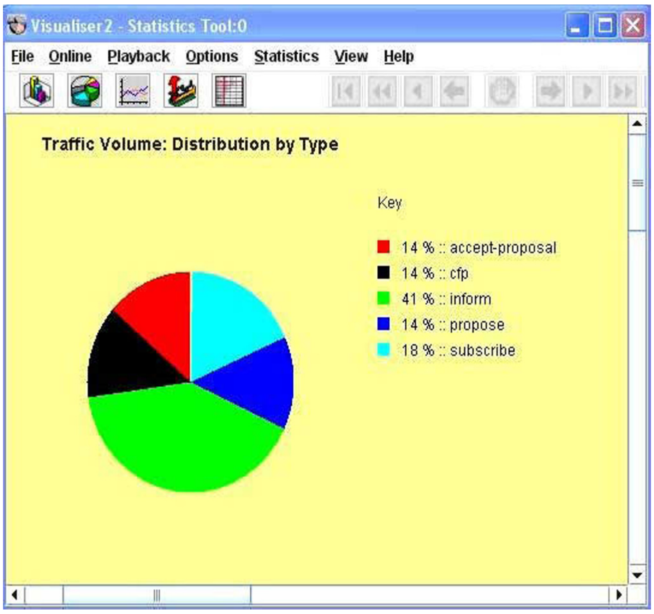

Fig. 8. The traffic volume- distribution by type of PPAPMS System in Zeus

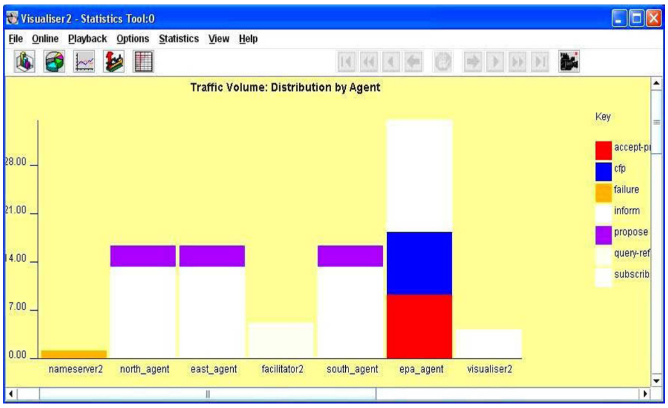

Fig. 9. The traffic volume- distribution by agent of PPAPMS System in Zeus

5. CONCLUSIONS

The paper presented a multi-agent system for air pollution monitoring in an urban area with power plants. The system was tested as a simulation and the possible chemical interaction among the air pollutants are ignored. The system is formed by agents that represent one local measurement units of Ploiesti city. Based on the real time measurement stored in databases there can be establish the local air quality index value as well as the general air quality index. The agents are solving the air pollution problems by using collaborative intelligence.

The experimental results showed that a multi agent system designed for the monitoring and analysis air quality around the power refineries can be useful for the environmental decision factors when an air pollution episode arise.

As a future work we shall use a sensors network for each agent in order to have a system able to perform the monitoring in real time. Furthermore, we shall build some data mining modules to generate predictions.

REFERENCES

Amato, A., Di Lecce, V., Pasquale, C., Piuri, V. (2005). “Wen Agents” in an environmental monitoring system. In *Proceedings of IEEE Int. Conf. on Computational Intelligence for Measurement Systems and Applications (CIMSA)*, 262-265. IEEE, Giardini Naxos, Italy.

Chappin, E.J.L., Dijkema, G.P.J. (2007). An agent based model of the system of electricity production systems: exploring the impact of CO2 emission-trading. In *Proceedings of IEEE Int. Conf. on System of Systems Engineering*, 1-5. IEEE, San Antonio, TX, USA.

Ćirić, I.T., Ćojbašić, Z.M., Nikolić, V.D., Živković, P.M., Tomić, M.A. (2012). Air quality estimation by computational intelligence methodologies. *Thermal Science*, 16(2), S555-S567.

Hussain, S., Islam, M.R., Shakshuki, E., Zaman, M.S. (2006). Agent-based petroleum offshore monitoring using sensor networks. In *Proceedings of DEXA '06*, 103-107. Krakow, Poland.

Lee, K.Y., Kim, B.-H., Velas, J.P. (2004). Development of an intelligent monitoring system with high temperature distributed fiber-optic sensor for fossil-fuel power plants. In *Proceedings of IEEE Power Engineering Society General Meeting*, vol. 2, 1989-1994. Denver, USA.

McArthur, S.D.J., Davidson, E.M. (2004). Multi-agent systems for diagnostic and condition monitoring applications. In *IEEE Power Engineering Society General Meeting*, vol. 1, 50-54.

Pavelescu, M., Pavelescu, A., Sandulescu, A. (2005). Nuclear power and the environment. *Rom. Journ. Phys.*, 50(5-6), 473-491.

Popescu, F., Ionel, I., Lontis, N., Calin, L., Dungan, I.L. (2011). Air quality monitoring in an urban agglomeration. *Romanian Journal of Physics*, 56(3-4), 495-506.

Riaño, D., Sànchez-Marrè, M., Roda, I.R. (2001). Autonomous agents architecture to supervise and control a wastewater treatment plant. In *Proceedings of IEA/AIE*, 804-811, Springer-Verlag.

Saleh, K., Nasser, N., AlYatama, A. (2012). Hierarchical and heterogeneous mobile agent-based wireless sensor networks (HHMA-WSN). *Proceedings of the 8th Int. Conf. on Computing Technology and Information Management (ICCM)*, vol. 2, 688-691, Seoul, Korea.

Seco, J.C., Correira, L., Pinto-Ferreira, C. (1998). A society of agents in environmental monitoring. *From Animals to Animats: Proceedings of the Fifth Int. Conf. on Simulation of Adaptive Behaviour*. Zürich, Switzerland.

Sujatha, K., Pappa, N., Kalaivani, A. (2011). Soft sensor for flue gas monitoring in power station boilers. In *Proceedings of the Int. Conf. Process Automation, Control and Computing (PACC)*, 1-6. Coimbatore, India.

Wile, J.H., Marron, S.T. (2006). Economic impact of new environmental rules on power systems. *Proceedings of IEEE Power Engineering Society General Meeting*

Yuval, Broday, D.M. (2009). Assessing the long term impact of power plant emissions on regional air pollution using extensive monitoring data. *Journal of Environmental Monitoring*, 11, 425-433.

Zhou, Z., Chan, W.K.V., Chow, J.H. (2007). Agent-based simulation of electricity markets: a survey of tools. *Artificiall Intelligence Review*, 28, 305-342.

Romanian Air Quality Monitoring Network, www.calitateaer.ro

Collins J., Ndumu D., *The Application Realisation Guide*, The Zeus Agent Building Toolkit, Intelligent Systems Research Group, BT Labs, May 1999

Oprea M., Matei A., Petre E., Agent-based Modeling of a Dam Monitoring System, *Proceedings of CSCS17*, vol. 2, 509-514, 2009.