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A MULTI -AGENT SYSTEM FOR MONITORING AND ANALYZING THE AIR QUALITY INDEX

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Abstract

There has been an increasingly awareness over the environmental impact of human activities, along with the exponential industrial growth, over the last decades. One of the negative important issues is the air pollution and its impact over the human health in recent years. Therefore, there have been initiated several laws and projects in order to monitor, analyze and forecast the evolution of the most important air pollutants. In this paper, it have been designed a multi agent system based model to simulate the distributed air quality monitoring process which can be used in the air pollution decision process. Each local monitoring station can be modelled as an intelligent agent and therefore the entire air quality network can be geographically distributed as a multi agent system. The experimental results show that intelligent agents can be successfully used in air quality monitoring and analyzing domain.

Keywords: Air Quality Index, air pollutants, intelligent system, multi agent system

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1. Introduction

Air pollution is considered a major environmental problem by the World Health Organization as a consequence of industrialization, urbanization, and fossil fuel use (World Health Organization, 2011). Therefore, public awareness of the air quality increased in the last years in developing and developed countries. Some of the air pollutants that can affect human health are carbon monoxide (CO), ozone (O₃), sulphur dioxide (SO₂), nitrogen dioxide (NO₂), particulate matter, size <10 μm (PM₁₀). High concentrations of these gases can cause respiratory infections, lung cancer, headache, dizziness and heart diseases. Thus, most developed countries have built air quality monitoring networks in order to analyze the air pollutants concentrations' evolution. Warnings are issued if there is some exceeding of the threshold values.

The Romanian Network for Air Quality Monitoring aims to measure and analyse the air pollutants' concentrations, to store the hourly recorded

data and to inform the authorities and the population regarding a possible pollution episode. This national monitoring network is formed by specialized stations based on the pollution source: traffic emissions, industry activity, and human settlements.

In addition to these national monitoring systems, there is a growing interest in designing different automated or/and intelligent systems such as the gas sensor network for air pollution monitoring tested in the laboratory room of Tokyo University of Agriculture and Technology (Tsujita and al., 2005), the Aeroflex, a bike for mobile air quality measurements designed in Belgium (Elen et al., 2013) or the GEMS project: a monitoring and forecasting system for atmospheric composition (Hollingsworth et al., 2008).

The utility of the statistical models in the environmental analysis has been also tested in many research works: the statistical models for the respirable suspended particular matter prediction in urban cities proposed by (Goyal et al., 2006), the modelling system for predicting urban air pollution

developed in Helsinki in 2000 (Karppinen et al., 2000).

Some applications of multi-agent systems in the environmental sciences have been reported recently in the literature in different domains: a small society of flying robotic agents (i.e. helicopter models) that collaborate for air pollution monitoring and analysis of a pollutant cloud around a power plant chimney proposed by (Seco et al., 1998), software Web Agents used in an environmental monitoring agent-based system as information providers for the other software agents that make different tasks (e.g. forecasting, brokering etc) in Amato et al. (2005) or MASE (Multiagent System for Environmental Simulation) described in Ralha et al. (2013), a multi-agent model system to characterize land-use change dynamics.

The main objective of the present paper is to design and test a suitable architecture of a multi agent based system for the air quality monitoring and analysing it in a specific region. Each local station can be modelled as an intelligent agent and therefore the entire network can be geographically distributed as a multi agent system. Furthermore, a local and regional air quality analysis is made using the national environmental standards.

The article, besides the Introduction, presents in section 2 the architecture, ontology and implementation of a multi agent system that is able to analyze Air Quality Index (AQI) value and a set of arguments that sustain the idea MAS is suitable for environmental issues models. Section 3 is dedicated to the implementation aspects of the multi agent based system proposed for air quality monitoring and analysis. There is also described the geographical area including the meteorological and air quality data used in this project. Next section of the article describes the preliminary experimental results and the paper's conclusions are presented in section 5.

2. AQDMASv1 multi agent system architecture

The fundamental element of a multi agent system is an intelligent agent: a computing system capable of performing an action independently without the need of support from other entities (including other agents) (Wooldridge, 2009). An agent

is characterized by autonomy, reactivity, pro-activity, and social ability. These agents are situated in an environment where they can interact through perception and action. Each agent has a representation of the environment and it takes decisions based on it (Fig. 1).

Architectures for intelligent agents that can be mentioned are: reactive architecture, deliberative architecture and hybrid architecture. Decision making in reactive architecture is implemented based on the perceptions and on some simple situation – action rules. The agents can adapt to changes in their environment without an internal representation of it. Deliberative architecture is a symbolic architecture in which the agents keep a complete representation of their environment. An example of this type of architecture is the model BDI (Beliefs, Desires, Intentions) whose main concepts are: Beliefs – the agent's information about environment, Desires – goals to be achieved, Intentions - aim chosen for the moment by the agent to be fulfilled, Plans – the methodology to fulfil a goal, Actions - how an agent can interfere with the environment.

The reasoning of a BDI agent assumes initially the existence of a purpose to fulfil. After an analysis of the realization possibilities, he chooses one according to certain criteria which become the intention of the agent. The agent beliefs act as a filter at all stages of the deliberative process (Pascal, 2011). For each goal there are several plans by which it can be achieved (the agent is flexible), so even if a plan fails it does not necessarily imply the system's failure (agent is robust).

Hybrid architectures combine the advantages of reactive and deliberative architectures and avoid their disadvantages (Oprea, 2010). Examples of hybrid architectures: Touring Machines, Interrap, PRS (Procedural Reasoning System).

A multi agent system is a collection of autonomous entities called agents which interact competitive or collaborative among themselves and with their environment to achieve individual and collective goals. Unlike traditional modelling techniques, a multi-agent system is not characterized by terms such as variables, functions and equations, but by notion like agents, objects and environment (Wang et al., 2012).

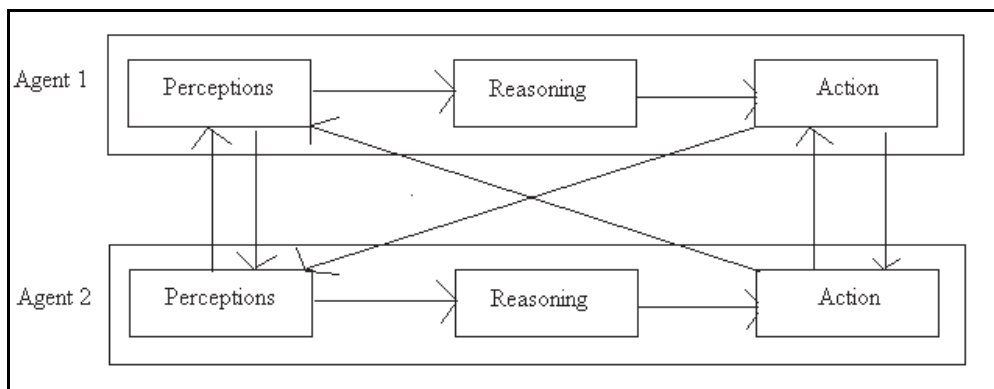


Fig. 1. The interaction between two agents and their environment

An air quality monitoring network assumes tracking continuously a set of air pollutants and meteorological factors as well as the long distance transmission and storing these values in specialized databases for the purpose of further analysis. Thus it is necessary to use a hierarchical structure partially geographically distributed (which has to meet economic and geographic requirements established by law), to monitor air quality in certain strategic points.

The issue of air pollution includes centralized modules (data servers and decision support services are located in local and national centres) and distributed modules (sensors for measuring atmospheric parameters are geographically distributed in monitoring stations). These features can be modelled using intelligent agents.

In Fig. 2 is presented the general architecture of an air quality monitoring and analysis network. The system shows a partially hierarchical distributed architecture which is structured on three levels: the local level where the values of atmospheric parameters are measured and are performed different operations such as validation and basic air quality analysis, the regional level composed of various regional centres that collect the data measured by specific area monitoring stations and the national level hierarchical located on the upper level which coordinates the operations performed in whole air quality monitoring system. Media communication between hierarchical levels can be GPRS wireless ZigBee. An intelligent agents based modelling is suitable for designing an air quality monitoring and analysis system because it can

provide those tools to implement a high level of flexibility for the system to adapt to the changes that take place in the distributed system, intentional (adding or removing of monitoring stations, of sensors and transducers) or unintentional (some disruption in the monitoring and analysis of air quality).

The monitoring system proposed in this paper implies the existence of intelligent agents both in the analysis subsystem (AS) and in the measurement subsystem (MS):

- At the local level, within the measurement subsystem (MS), each intelligent agent is connected to a sensor or transducer;
- At local level, within the analysis subsystem (AS), each entity that coordinates a monitoring station and calculates local air quality index is designed also as an intelligent agent;
- At regional level, within the analysis subsystem, there is an intelligent agent that coordinates the data centralization from local stations in order to achieve regional air quality analysis. Another intelligent agent can incorporate data mining techniques to forecast an air pollutant concentration;
- At national level, the information submitted by the regional centres necessary for calculating the overall air quality index is centralized by an intelligent agent. A data mining agent may be included to predict a national evolution of a certain air pollutant.

In the present case, applying the intelligent agents' concept to build a monitoring and analyzing air quality system has several advantages over the traditional approaches.

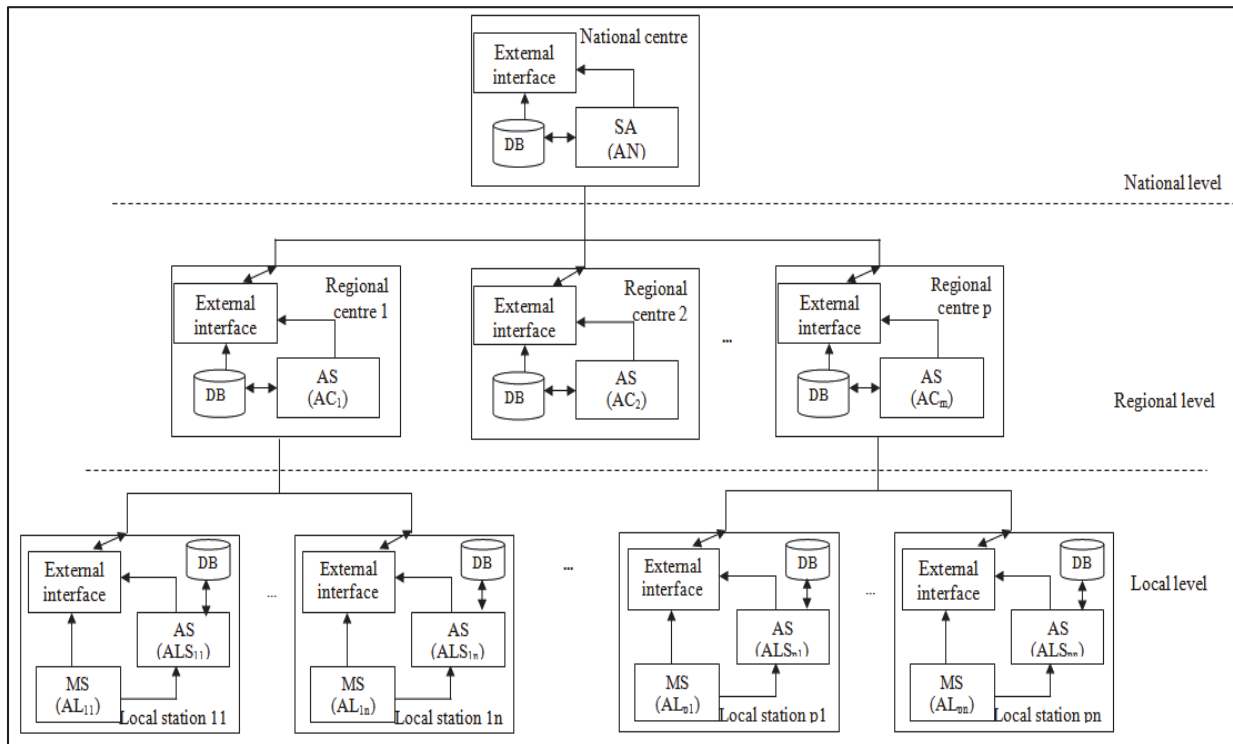


Fig. 2. The multi agent based system proposed architecture (Dragomir, 2014a) (where: n- number of local monitoring stations, m- number of atmospheric parameters monitored, p- number of regional centres, DB – database, AS – analysis subsystem, MS – monitoring subsystem)

At first, we can mention the unit's autonomy. Depending on their goals, the agents in the monitoring and analysing system can behave autonomously in their environment. Secondly, the increased reliability and robustness of the system is taken into consideration. In case one of the local agents fails, the other agents adapt and continue the system functions (Wooldridge, 2009). In the same manner we can reveal that the system allows agents to be added or deleted at any time. Another important advantage is the agents' capability of learning. Agents can learn from their past actions and behaviours (this characteristic is not implemented in this study). The system collaboration is coordinated by the National

Agent (NA), which is responsible for initiating cooperation, sharing purpose in lower divisions, the preparation of the general plan of the system, and allocating each subplan by a team of agents located in a region. In Table 1 are presented the system's agents and their description. Agents AL_{11}, \dots, AL_{nm} present a reactive architecture not being necessary to have a representation of the environment. There are sufficient some execution rules (e. g. Rules that checks the operability of the transducer) while the other types of agents have a deliberative architecture. In Table 2 are presented the agents' tasks. Each task is composed of a series of actions defined for the proposed system in Table 3.

Table 1. The agents of the system (Dragomir, 2014a)

Agent	Description	Agent architecture
AL_{11}, \dots, AL_{nm}	Local agents situated in the measurement subsystem	Reactive architecture
ALS_1, \dots, ALS_n	Local agents situated in the analysis subsystem	Deliberative architecture
AC_1, \dots, AC_p	Regional coordinators agents situated in the analysis subsystem at the regional level	Deliberative architecture
ADM_1, \dots, ADM_p	Regional Data mining agents situated in the analysis subsystem at the regional level	Deliberative architecture
ADM	National data mining agent situated in the analysis subsystem at the national level	Deliberative architecture
AN	National agent situated in the analysis subsystem at the national level	Deliberative architecture

Table 2. The tasks of the agents

Agent	Task
AL_{11}, \dots, AL_{nm}	Measure atmospheric parameters()
ALS_1, \dots, ALS_n	Create local station report()
AC	Create regional report()
AN	Create national report()
ADM	Create DMmodel()

Table 3. The actions (Dragomir, 2014a, 2014b)

Action	Description
$create(regional_report_k_from(SM_1, SM_2, \dots, SM_n))$	Create the regional report k using the local reports from monitoring stations SM_1, SM_2, \dots, SM_n
$create(general_report_from(RR_1, RR_2, \dots, RR_p))$	Create the general report from the regional report RR_1, RR_2, \dots, RR_p
$create(local_report_i_from(ms^i_1, ms^i_2, ms^i_3, \dots, ms^i_m))$	Create the local report from monitoring station i using the measured data $ms^i_1, ms^i_2, ms^i_3, \dots, ms^i_m$
$store(database;(date, hour, ms^i_1, ms^i_2, ms^i_3, \dots, ms^i_m))$	Store the measured data $ms^i_1, ms^i_2, ms^i_3, \dots, ms^i_m$ in the specialized database from monitoring station i
$measure(parameter_j(SM_i))$	Measure the value of atmospheric parameter j at monitoring station SM_i $i = \overline{1, n}, j = \overline{1, m}$
$send(parameter_l(SM_i, ALS_i))$	Send the parameter l value from station SM_i to ALS_i
$store(database;(date, hour, ms^i_1, ms^i_2, ms^i_3, \dots, ms^i_m))$	Store in the local database i the measured values $ms^i_1, ms^i_2, ms^i_3, \dots, ms^i_m$
$initiate_request(resources_for(i, r))$	Agent i initiates a request for the needed resources to create r
$get(r)$	Get the resource r
$is_working(Tr)$	Check if the transducer Tr is working
$build(model_i(p_BDC))$	Build the data mining model i based on the generating database parameters
$store(model_i(p_BDC, p_model, predict_model))$	Store the model i with the generating database parameters (p_BDC), the model parameters (p_model) and the model predicted value (predict_model)
$test(model_i(p_BDC, p_model, predict_model))$	Test the model i
$send(model_i(p_BDC, p_model, predict_model), j)$	Send the testing results of model i to the agent j
$show(results(model_i(p_BDC, p_model, predict_model)))$	Display the results of model i

Table 4. The system’s ontology (Dragomir, 2014a)

<i>Concept</i>	<i>Attribute</i>	<i>Restrictions</i>
Air pollutant concentrations: SO₂, NO, NO₂, NO_x, PM₁₀, CO, O₃, m-xylene, p-xylene, o-xylene, benzene, 1,3-butadiene, toluene, ethylbenzene	Value: Real	-
Meteorological parameters value: temperature, precipitations, wind speed, pressure, solar radiation	Value: Real	-
Meteorological parameters value: wind direction	Value: Real	Value ∈ (0,360)
Meteorological parameters value: relative humidity	Value: Real	Value ∈ (0,100)
Local report	AQI: Integer	AQI ∈ {1,2,3,4,5,6}
Regional report	AQI _{regional} : Integer nr_region: Integer	AQI _{regional} ∈ {1,2,3,4,5,6} nr_region ∈ {1,..p}
General report	AQI _{general} : Integer nr_station: Integer	AQI _{general} ∈ {1,2,3,4,5,6} nr_station ∈ {1,..n}

2.1. The system ontology

System ontology includes declarative knowledge of an area representing key concepts. They are characterized by a name and a set of attributes identified by name, data type, default value and any restrictions (Collins and Ndumu, 1999b). Some of the proposed system’s concepts are related to the measurement and analysis concentration values of air pollutants and meteorological factors, while the other relates to the contents of the local and general reports. Entities have attributes related to: quantity, concentration, value, and certain restrictions set out in Table 4.

2.2. The agents and their tasks

This section describes the system agents, presented briefly in Table 2. The generic algorithms for each type of agent include their responsibilities and actions.

2.2.1. Local agent

Local agents are designed to retrieve data on the status of atmospheric dispersion process (Fig. 3). They are connected to sensors (automatic devices for reading the values of atmospheric parameters and meteorological factors) of an air quality monitoring station. The measurement is initiated by a request received from local supervisor agents. Rules that can be used by a local agent with a reactive architecture can refer to the state of the transducer on which it is connected or to the measured values transmission possibility. Rules example:

Measurement rule M1: IF the sensor is inoperative THEN display warning message.

Measurement rule M2: IF the measured value is invalid THEN resume measurement.

Actions performed in a local agent’s task (Algorithm 1) are: is_working (Tr), measurement (parameter₁ (SM_l)) and send (parameter₁ (SM_l, ALS_l)).

2.2.2. Local supervisor agent

Local supervisor agent requests atmospheric parameters data to the local agents and generates the local air quality report, based on it. Results are sent to

the regional coordinator agent in order to create the regional air quality report (Algorithm 2).

Heuristic rules that can guide this type of agent activity can include comparisons of certain air pollutants concentrations values to the air quality index classification thresholds presented in Table 7), values used furthermore in other analyzes on air quality.

Example of heuristics rules:

Analysis Rule RI1: **IF** value_{CO} > 3 **And** value_{CO} < 4, (9) **Then** AQI_{CO} = 2.

Analysis Rule RI2: **IF** value_{NO} > 100 **And** value_{NO} < 139, (9) **Then** AQI_{NO} = 3.

Analysis Rule RI3: **IF** value_{PM10} > 50 **And** value_{PM10} < 99, (9) **Then** AQI_{PM10} = 5.

A local supervisor agent’s task includes the following actions: initiate_request (resources_for (i, r)), store (database_i (date, hour, msⁱ₁, msⁱ₂, msⁱ₃, ..., msⁱ_m)) and create (local_report_i_from (msⁱ₁, msⁱ₂, msⁱ₃, ..., msⁱ_m)).

2.2.3. Regional coordinator agent

Regional coordinator agent is the agent who communicates with the national agent in order to receive the global system goal. To create the regional report he finds the agents that can help him to fulfil its goal and contact them for certain tasks such as local reports.

Regional coordinator agent generates regional air quality index, as the higher of local indexes based on reports from local supervisors. In Algorithm 3 there is presented the task of this agent which includes the action create(regional_report_k_from(SM₁, SM₂, ..., SM_n)).

2.2.4. National Agent

National Agent receives the requirements that need to be fulfilled from outside the system. To achieve general report, he must find agents that can help in carrying out certain tasks such as regional reports. He calculates the general air quality index, as the higher of regional indexes based on regional coordinator agents’ reports. The result contains beside the index, the number of the region or regions where the maximum value was recorded (Algorithm 4). The task is based on the action create (general_report_from(RR₁, RR₂, ..., RR_p)).

2.2.5. Data Mining Agent

Data Mining Agent is responsible for building and testing models specified by the user in the interface. It receives information about database used to create the forecasting models, such as codes of the selected models, the variable chosen for prediction, the period and station that recorded data used for prediction, and parameters needed for testing models (records from a particular day and time of a specific station).

Using data mining algorithms, he builds the required models. Their parameters are stored in a specialized database. Predicted value of pollutant is sent to the coordinator or national agent (Algorithm 5).

The data mining agent task contains the actions: build(model_i(p_BDC)), store(model_i(p_BDC, p_model, predict_model)), test(model_i(p_BDC, p_model, predict_model)), send(model_i(p_BDC, p_model, predict_model), j).

Algorithm 1. The local agents' task

```

Inputs: -
Outputs: Pij – the value of atmospheric parameter j at station i, i=1÷n, j=1÷m
Function measure atmospheric parameters()
begin
    transducer_state ← -9999;
    start measurement
    if transducer_state = -9999 then //inoperative transducer
        Pij ← -9999
        display_message("inoperative transducer")
    else // functional transducer
        Pij ← measured value;
        send value Pij
    end
end
    
```

Algorithm 2. The local supervisor agents' task

```

Inputs: m – number of atmospheric parameters measured at station i;
        Pj, j=1÷m – the concentration value measured for parameter j at station i;
        P1j, P2j, P3j, P4j, P5j – the thresholds for air pollutant j
Outputs: local report (AQIj, j=1, m – air quality index for air pollutant j)
function create_report_station(nr_station, day, month, year, hour, local_reporti)
begin
    initiate_request(resources_for(i, r))
    for j ← 1 to m do
        if Pj <> null then mp=mp+1;
    end
    if mp >= 3 then
        for j ← 1 to m do
            if Pj < P1j then AQIj ← 1
            else
                if Pj < P2j then AQIj ← 2
                else
                    if Pj < P3j then AQIj ← 3
                    else
                        if Pj < P4j then AQIj ← 4;
                        else
                            if Pj < P5j then AQIj ← 5
                            else AQIj ← 6
                        end
                    end
                end
            end
        end
        local_reporti.AQI ← get_maximum(AQI1, ..., AQIm)
    else local_reporti.AQI ← 0 // there are less than 3 parameters
        //measured and the air quality index
        //cannot be determined
    end
    return local_reporti;
end.
    
```

Algorithm 3. The regional coordinator agent's task

```

Inputs: local_reporti, i=1÷n, - local report from monitoring station i
Outputs: regional report (AQIregional, nr_station - vector)
function create_regional_report(day, month, year, hour, regional_report)
begin
    ziua ← the day of the server
    luna ← the month of the server
    an ← the year of the server
    ora ← the hour of the server
    maximum_index ← get_maximum(local_report1.AQI, ..., local_reportn.AQI)
    poz ← 0
    for i ← 1 to n do
        if local_reporti.AQI = maximum_index then
            poz ← poz+1
            regional_report.nr_station[poz] ← i
            regional_report.AQI ← maximum_index
        end
    end
    return regional_report
end.
    
```

Algorithm 4. The National Agent's task

```

Inputs: regional_reporti, i=1÷p, - regional report from region i
Outputs: general_report (AQIgeneral, nr_region - vector)
function create_general_report(day, month, year, hour, general_report)
begin
    ziua ← the day of the server
    luna ← the month of the server
    an ← the year of the server
    ora ← the hour of the server
    maximum_index ← get_maximum(regional_report1.AQI, ..., regional_reportp.AQI)
    poz ← 0
    for i ← 1 to p do
        if regional_reporti.AQI = maximum_index then
            poz ← poz+1
            general_report.nr_station[poz] ← i
            general_report.AQI ← maximum_index
        end
    end
    return general_report
end.
    
```

Algorithm 5. The task of the data mining agent

```

Inputs: p_model(nr_model, predicted_variable)
        - nr_model is an array with the selected models code,
        predicted_variable – the selected variable to forecast;
        p_BDC (period, station, pollutant) – the building model database parameters;
        p_test (day, month, year, hour, station)- the model testing parameters.
Outputs: values_parameters_model – hash table with the prediction parameters for every selected model;
        forecast_model – array with the forecast results for every model.
Function create_DMmodel(p_BDC, p_model, values_parameters_model, predict_model)
begin
    nr ← the nr_model array dimension
    dim – number of the model parameters
    for i ← 1 to nr do
        build(modeli(p_BDC))
        store(modeli(p_BDC, p_model, predict_model)),
        for j ← 1 to dim do
            calculate_parameter(values_parameters_model[j])
            store_BD(i, values_parameters_model[j])
        end
        predict_model ← test(i, p_testare)
    end
    return predict_model
end.
    
```


2.3. Interaction protocol and communication among the agents

The way the agents interact among them in order to fulfil their goal is more than a simple exchange of messages; it must be conducted according to rules and schedules (interaction protocol).

The interactions of some of the system agents can be seen in Fig. 3. The agents' coordination should be done following two types of execution:

- Sequential (e. g. the national agent takes over the system goal from the interface, the general air quality index is calculated);
- Parallel (communication between regional and local level are carried out in parallel threads, also at the local level are initiated multiple threads for each monitoring station).

Communication between agents is achieved through a collaborative specialized language based on special protocols for communication between intelligent agents, FIPA ACL. A FIPA ACL message has a standard structure containing different attributes. When a new message is sent to, an object is instantiated and its attributes are completed, their number varying according to the message content.

3. AQDMASv1 implementation

In this paper, there are described the preliminary experimental results of the AQDMASv1 system. This system covers only one region (Ploiesti – a Romanian city) from the general air quality monitoring and analysis network, proposed in Fig. 4. It presents six air quality monitoring stations that are part of the National Network for Monitoring Air Quality. There was developed a multi agent system that is designed to simulate an air quality monitoring, analysis and prediction network of intelligent agents.

This experiment scope is to simulate on a single computer the activity in a network consisting of six monitoring stations.

Therefore, in this case study, the parameters p, n, and m have the values: p=1 (there is only one regional centre) n=6 (there are 6 local stations), m=22 (the atmospheric parameters monitored in Ploiesti are 22) and the user of the system is a human.

In this project, the ZEUS framework that conforms to FIPA standards is used. Agents can be placed on a single computer or distributed on several computers, yet the implementation, the code for sending and receiving messages is the same. The ZEUS runtime executes within a Java Virtual Machine (JVM) as well as Weka, data mining specialized software (Collins and Ndumu, 1999b). It has been used the source algorithms implemented in Weka, in order to apply artificial intelligence techniques for the data mining agent.

3.1. Study area

The city of Ploiesti is located 60 kilometres North of Bucharest, the capital of Romania. There are 201,226 people living within Ploiesti, making it the 9th most populous city in Romania, according to the 2011 Romanian census (Table 5). It is an industrial city for which the petrochemical and chemical industries are the main contributors to environmental pollution. Furthermore, the winter lower precipitations along with the frequent atmospheric calm (the wind velocity is 0 m/s) and thermal inversions during this period contribute to maintaining a high level of air pollution. The city topography is another factor that can negative influence the air quality: being a plain terrain surrounded by hills there is a reduced air currents movement which prevents pollutants' dispersion.

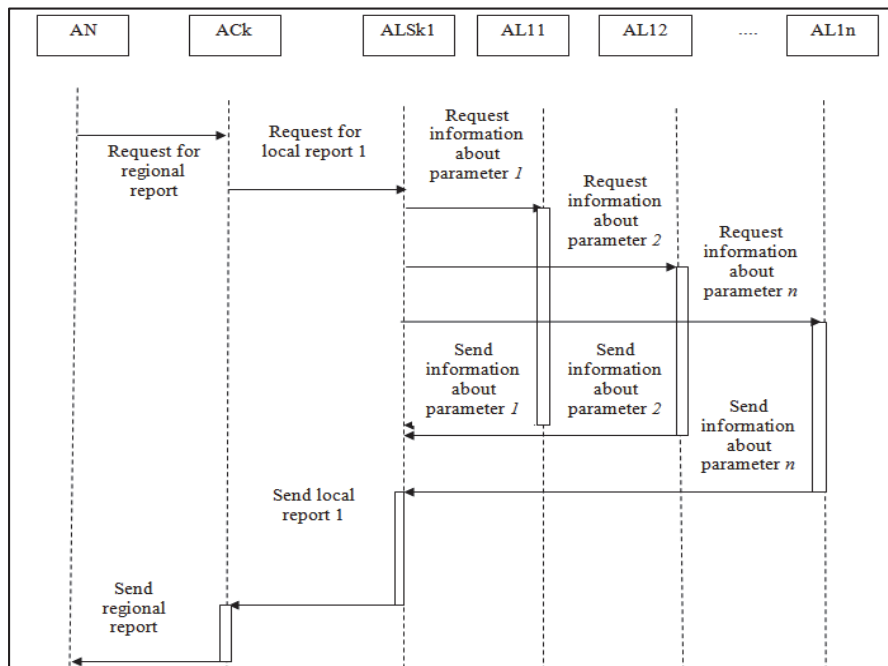


Fig. 3. The interaction diagram among the agents

Table 5. Information about the locality

Name	Ploiesti
County	Prahova
Country	Romania
Coordinates	44° 56'24" North latitude 25° 2' 48" East longitude
Altitude	~160 m
Terrain	Plain, surrounded by hills
Clime	Continental
Mean annual temperature	10.5°C
Mean annual precipitations	600 l/m ²
Mean annual wind velocity	1.8 m/s

3.2. Air quality data

The hourly air quality data of carbon monoxide (CO), sulphur dioxide (SO₂), nitrogen monoxide (NO), nitrogen dioxide (NO₂), nitrogen oxides (NO_x) particulate matter (PM₁₀), and ozone (O₃), benzene, toluene, o-xylene, m-xylene, p-xylene, ethylbenzene, 1,3 butadiene, over a period of 3 years (from January 2009 to December 2011) has been used. A shorter period would not be relevant in this study. As a future research we will take into consideration the fact that a longer period will make the models more accurate. The measurement methods used for each air pollutant and meteorological parameter as well as their units are presented in Table 6.

3.3. Meteorological data

As highlighted by (Boian et al., 2009), some of the meteorological parameters have great influence over a possible pollution episode. The dispersion and

diffusion of air pollutants which enter the atmosphere, occurs in accordance with the laws of turbulent diffusion that depends on vertical distribution of temperature (thermal stratification) and wind velocity. Other phenomena that can increase the pollutants concentrations even 2 or 3 times are: precipitation, fog, gravitational sedimentation of large particles, chemical and photochemical reaction between different substances.

In this study there are used the recorded data at the same 6 monitoring stations in the same period of time of wind direction (deg), wind speed (m/s), temperature (deg C), relative humidity (%), pressure (mbar), solar radiation (W/m²), precipitations (mm).

3.4. Data set

There were created 6 databases with hourly recorded value for all the atmospheric parameters mentioned above, each one for a monitoring station. Furthermore, there was calculated the AQI (Air Quality Index) with a classic formula, used currently in the National Network for Air Quality Monitoring from Romania. According to www.calitateair.ro (2014), to assess the air quality status and its possible effects on human health the index values used in Romania cities reflect six different ranges, illustrated in Table 7.

There are determined the AQI for each pollutant and furthermore as a general AQI is calculated the maximum index among these. BDS1,...BDS6 represent the databases located in monitoring station 1,...,6and BDC represent the database with information regarding the region air quality index. The structure of the tables from BDS5 and BDS1 database include: date, time, CO, SO₂, NO_x, NO, NO₂, PM₁₀, O₃, benzene, toluene, o-xylene, m-xylene, p-xylene, ethyl benzene, 1,3-butadiene, the air quality index.

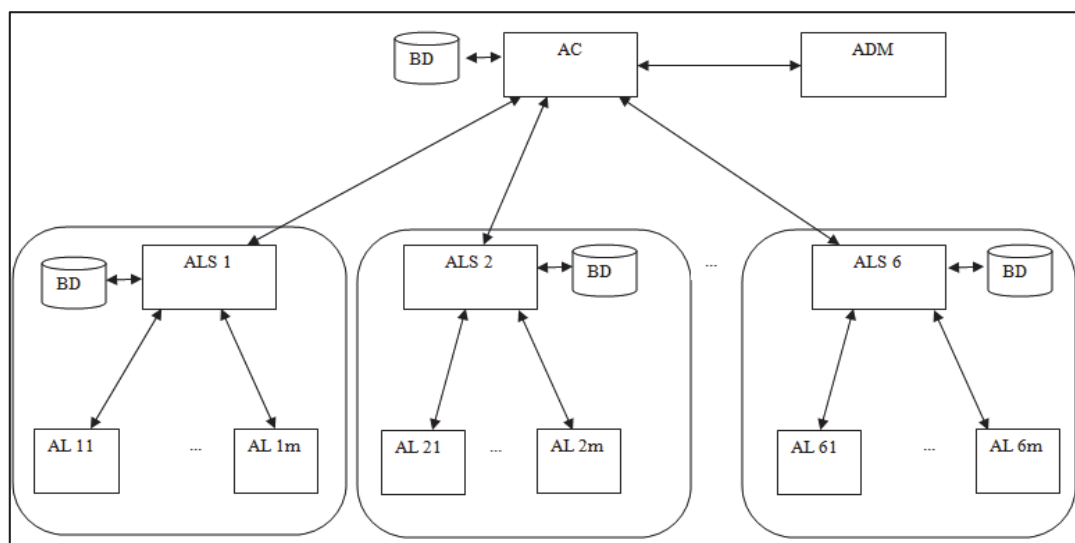


Fig. 4. The multi agent system proposed architecture

Table 6. Information about the measured variables

Measured variable	Measurement Method	Unit
SO ₂	UVFL [UV – fluorescence]	µg/m ³
NO ₂ , NO, NO _x	CHLM [chemiluminescence]	µg/m ³
benzene, toluene, o-xylene, m-xylene, p-xylene, ethylbenzene, 1,3 butadiene	GC – MS [Gas chromatography- mass spectrometry]	µg/m ³
O ₃	UVABS [UV- absorption]	µg/m ³
CO	IRABS [IR corel. Absorption spectrometry]	mg/m ³
PM ₁₀	GV[gravimetric]	µg/m ³

Table 7. The concentration domains for each quality index (www.calitateaer.ro, 2014)

Air quality index (Indice de calitate)	Descriptor	SO ₂ (µg/m ³)	NO ₂ (µg/m ³)	O ₃ (µg/m ³)	CO (mg/m ³)	PM ₁₀ (µg/m ³)
1 (excellent)	Excellent	0 – 49.(9)	0 – 49.(9)	0 – 39.(9)	0 - 2.(9)	0 - 9.(9)
2 (foarte bun)	Very good	50 – 74.(9)	50 – 99.(9)	40 – 79.(9)	3 - 4.(9)	10 -19.(9)
3 (bun)	Good	75 – 124.(9)	100–139.(9)	80 – 119.(9)	5 - 6.(9)	20 – 29.(9)
4 (mediu)	Moderate	125–349.(9)	140–199.(9)	120–179.(9)	7 – 9.(9)	30 – 49.(9)
5 (rau)	Poor	350–499.(9)	200–399.(9)	180–239.(9)	10 – 14.(9)	50 – 99.(9)
6 (foarte rau)	Severe	>500	>400	>240	>15	>100

Database tables of stations 2, 3 and 4 have the following structure: date, time, CO, SO₂, NO_x, NO, NO₂, PM₁₀, O₃, benzene, toluene, o-xylene, m-xylene, p-xylene, ethyl benzene, 1,3-butadiene, wind direction and speed, temperature, relative humidity, atmospheric pressure solar radiation, precipitation, air quality index.

In the AQDMASv1 system the databases are:

The Table of station 6 database has the following structure: date, time, CO, SO₂, NO_x, NO, NO₂, PM₁₀, O₃, wind direction and speed, temperature, relative humidity, atmospheric pressure, solar radiation, precipitation, air quality index.

The coordinator agent’ database Table includes: date, time, air quality index 1 air quality index 2, air quality index 3, air quality index 4, air quality index 5, air quality index 6, and general air quality index.

For the data mining agent there was implemented a single database BDM used to build the data mining models. There are stored data regarding the data mining technique, the running parameters and the experimental results. To integrate MySQL in Zeus there was used JDBC (Java Database Connectivity). Access to the database is via specific driver MYSQL named org.gjt.mm.mysql.Driver. After JDBC driver has been registered, it can be used to establish a connection to the database, getConnection () from DriverManager class. Once the connection created, a Connection object can be used to instantiate objects of type Statement by which SQL statements can be sent to the database. In the end all connections to the database will be closed.

4. Results and discussion

This preliminary experiment highlights the monitoring and analysis aspects of this system. Thus, from the system interface shown in Fig. 5, the user can select the monitoring station and the parameters

specific to each monitoring station to be considered for analysis from the left side of the interface.

In the example given in Fig. 5 only PH2 and PH3 stations are selected, each with the following air pollutants: SO₂, NO₂, PM₁₀, O₃ and CO. Other options for air parameters are: NO, NO_x, benzen (benzene), toluen (toluene), o-xilen (o- xylene), m- xilen (m-xylene), p-xilen (p-xylene), etilbenzen (ethyl benzene), 1,3 butadiena (1,3-butadiene), temperatura (temperature), precipitatii (precipitation), presiunea atmosferica (atmospheric pressure), directia vantului (wind direction), viteza vantului (wind speed), radiatia solara (solar radiation), umiditatea relativa (relative humidity).

There are shown also the benchmarks (first table in the right side of interface) and the measurements values of the atmospheric parameters selected (the second table), the general air quality index and a graphical representation showing the last month evolution of the general air quality index. The graphic is generated using information stored in the coordinator agents’ database.

In the example were involved 15 agents out of 140 (22 atmospheric parameters x 6 stations + 1 local agent supervisor x 6 stations + 1 coordinator agent + 1 agent data mining) deployed to monitor air quality at six monitoring stations. Communication between agents can be viewed in Fig. 6a.

In ZEUS, once the task agents are created, there are generated three different utility agents: Nameserver (an important agent that knows each agent’ IP address), Visualizer (an optional agent but very useful if we want to generate different statistics related to the system evolution) and Facilitator (an agent that informs the others about the tasks performed by the each agent).

One of the Visualiser feature is the possibility to track the messages exchanges among agents in real time. This can be observed in the Agent Society Tool presented in Fig. 6a.

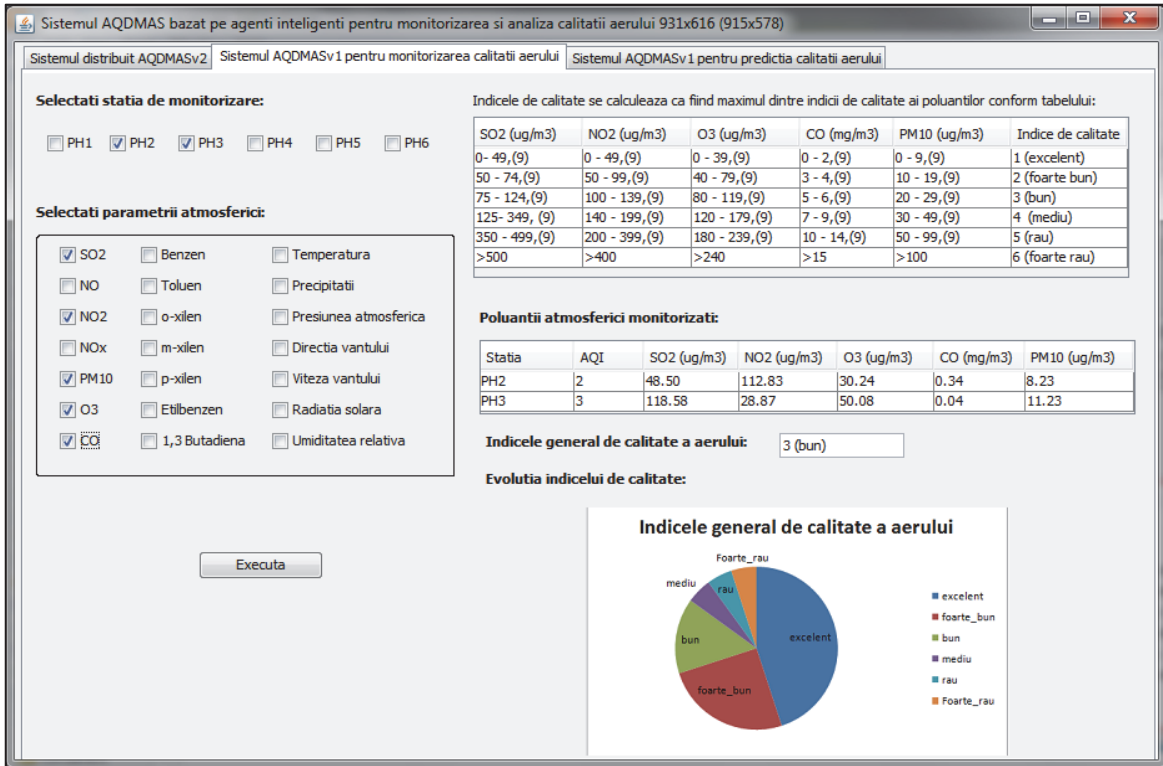
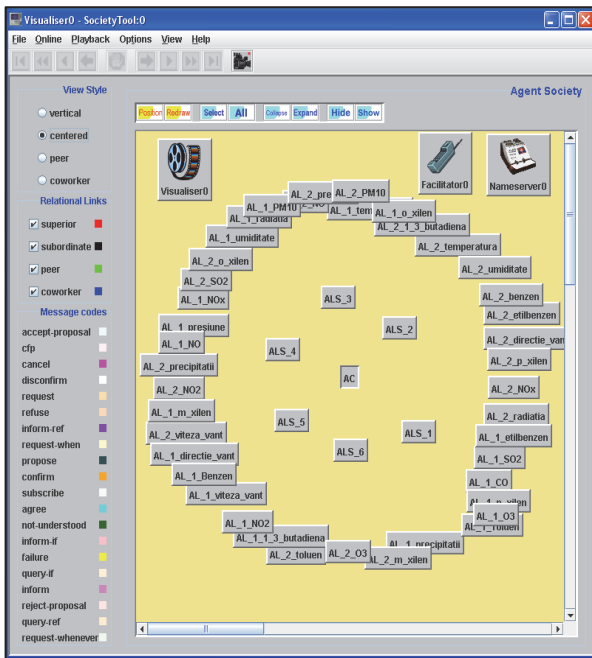
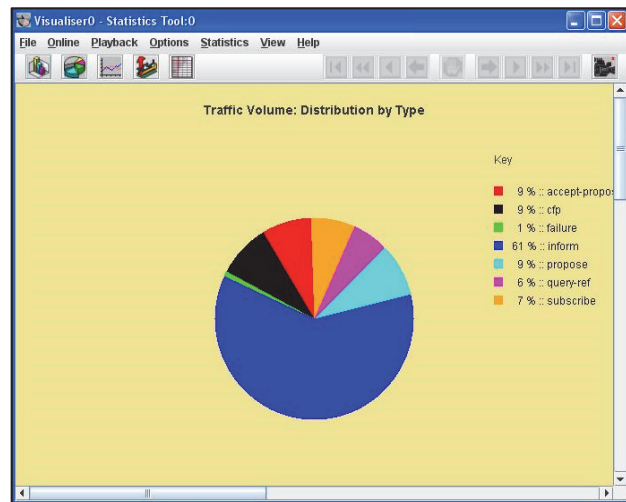


Fig. 5. The multi agent system user interface



(a)



(b)

Fig. 6. (a) The multi agent system agent society; (b) The multi agent system traffic volume messages distributed by type

Fig. 6b highlights the interactions among the agents: the messages sent are 7% to *subscribe* (to ask the Facilitator which task is performed by which agent), 9% *call for propose* and 9% *propose* (the supervisor agent asks the other agents to send the information needed). 9% *accept-proposal* (with no negotiation the agents accept to fulfil the request) and 61% to *inform* (in order to achieve the general goal, the agents send the information requested).

5. Conclusions

In this paper, it is proposed the development of a modelling multi agent system for air quality monitoring and analysis. The intelligent agents can be successfully used in a distributed monitoring system presenting important advantages comparing to the traditional approaches like autonomy of the agents, the increased reliability and robustness of the system.

There were designed five types of agents distributed across the monitoring network: local agents connected to automatic devices for reading the values of atmospheric parameters and meteorological factors, local supervisor agents generate the local air quality report, regional coordinator agents generate regional air quality index, as the higher of local indexes based on reports from local supervisors, national agent calculates the general air quality index and a data mining agent which is responsible for building and testing data mining forecast models. For each agent type there were presented the specific actions, tasks, interactions.

The experimental results show that the proposed system can be integrated in a classical air quality monitoring and analysis system used by the National Environmental Protection Agency. It provides real-time data, reducing execution times. Also, agents' autonomy is an important feature of AQDMASv1 system which recommended it for use in automated systems, because once the purpose of the system is set, each agent will "know" what to do without outside intervention by the user. As future work, we can mention the designing of a distributed over several computers of this multi agent system and testing its real time capabilities.

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