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Intelligent Environments Approaches Applied in Water Management

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Abstract. Recently, we are in the époque of sophisticated *Ambient Intelligence (AmI)* applications, mainly based on utilisation of wide sensor networks together with advanced AmI approaches. If we concentrate on environmental (that is, open space or outdoor) applications, there is just a few of them, although basically focused on environmental monitoring, that enable more functionalities than just collecting environmentally related data and passing them to further elaboration. In our paper we intend to go further on with the ideas how environmentally oriented wireless sensor networks used in "large-scale" throughout the open natural environment could be enhanced using some recent AmI approaches in order to be beneficial in preventing primarily environmentally related problems, if not even disasters. We focus our attention on the area of water management with accent on two critical water related problems: floods management and drought-stricken periods. We suggest a concept of an approach how to solve a particular water management problem in Czech Republic using large-scale ambient intelligence approach enhancing thus wireless sensor network focused on environmental monitoring.

Keywords. Ambient intelligence, wide area sensor networks, large-scale applications, intelligent outdoor spaces, outdoor workplaces

1. Introduction

Recent sophisticated *Ambient Intelligence (AmI)* applications, mainly based on utilisation of wide sensor networks together with advanced AmI approaches, deserve to be used widely because of their benefits for big palette of users. However, when focusing on environmental (that is, open space or outdoor) applications, there is just a few of them, although basically focused on environmental monitoring, that enable more functionalities than just collecting environmentally related data and passing them to further elaboration. Such applications are closely related to the notion of "Large-scale Ambient Intelligence", firstly introduced in [1].

According to [2], recent advances in micro-electro-mechanical systems and in low-power wireless network technology have created the technical conditions for building multi-functional tiny sensor devices, which can be used to observe and to react according to physical phenomena of their surrounding environment. Wireless sensor nodes are recently evolved in low-power devices equipped with processor, storage, a power supply, a transceiver, one or more sensors and if necessary, also with an actuator. Several types of sensors can be attached to wireless sensor nodes. These wireless sensor devices are small and they are cheaper than the regular sensor devices.

As Akyildiz and others [3] pointed out, the wireless sensor devices can automatically organize themselves to form an ad-hoc multi hop network. Wireless sensor networks may be comprised by hundreds or thousands of ad-hoc sensor node devices, working together to accomplish a common task. Self-organizing, self-optimizing and fault-tolerant are the main characteristics of this type of network.

Environmental monitoring applications can be categorized into indoor and outdoor monitoring [2]. According to them, indoor monitoring applications typically include buildings and offices monitoring. These applications involve sensing temperature, light, humidity, and air quality, but also fire and civil structures deformations detection. From our point of view, outdoor monitoring applications are much more interesting and still having a serious potential for further exploitation. Outdoor monitoring applications include chemical hazardous detection, habitat monitoring, traffic monitoring, earthquake detection, volcano eruption, flooding detection and weather forecasting, among others. Environmental wireless sensor networks also have found their applicability in agriculture with soil moisture and temperature monitoring as the most important applications.

In our earlier papers [4], [5] and [6] we started with some contemplations related towards possibilities of using ambient intelligence approaches in water management. In our recent papers [7], [8], [9] or [10] we concentrated our research on several scenarios how outdoor oriented applications of environmental wireless sensor networks could be enhanced by recent approaches from the area of Ambient Intelligence in order to enable an outdoor environment to be a smart environment in a well-defined sense.

In this paper, we present some contemplation about possibilities for outdoor large-scale ambient intelligence focused on areas, where environmental catastrophes with disastrous effects could appear, with main accent on the water management area. We define a particular practical problem and an outline of its solution .

2. The Problem

One of the important problems that seem to be suitable for solving by large-scale ambient intelligence approaches is monitoring a river watershed. The aim of a project investigated a couple of years ago [4] was the development of a system that could help the watershed managers who make decisions about the most suitable manipulations on the reservoir Nyrsko and on the river Uhlava in South-western Bohemia in the Czech Republic. Although the reservoir Nyrsko is relatively small (approximately 142 000 m2) and the river Uhlava is no longer than 110 km, the problem of reservoir and river control is interesting enough, because Nyrsko is the only resource of drinking water for over 180 000 inhabitants of the town Pilsen. As this resource of water lays 100 km up on the stream from Pilsen, the task of effective and economical manipulations is non-trivial. The main obstacle comes from the time delay between the manipulation on the reservoir and the manifestation of the manipulation in Pilsen (3-7 days). That is why all requirements for reducing or increasing of the consumption of water from the river Uhlava have to be defined in advance. In the same time the weather forecasts for several next days have to be taken into account in the process of manipulation formulation, because heavy rainfalls or dry periods can radically change the flow rate in the river and its inflows and thus the significance of manipulations gets even clearer. The other kind of obstacles is related to the pursuit of fulfilling contradictory requests of different customers of the water management company, who are owners of electricity power plants, fishers, managers of water sport events, industrial companies that consume water from the river Uhlava etc. The whole situation is schematically depicted in Fig. 1.

Fig. 1. Scheme of the real watershed situation.

The developed system [4] was capable of supporting watershed managers' decisions about the manipulations on the reservoir Nyrsko and on the river Uhlava. However, a few years ago, we can think about an enhancement of the system by adding a functionality of producing early warning messages in critical situations such as approaching storms with possible flesh floods, or very fast gradient of the river surface level increase possibly resulting in a flood danger. This paper describes some possible approaches how adding of these new functionalities could be possible.

3. Related Works

3.1. Wireless Sensor Networks

When thinking about enhancement of the above mentioned system aiming of a river basin dispatchers' decisions support, the first possible approach seems to be in employing a large-scale intelligent sensor network as a basis for an enhanced system.

Tremendous effort has been devoted recently to the area of sensor networks and their important applications, as mentioned in [11] or [2]. A wireless sensor network is usually a combination of low-cost, low-power, multifunctional miniature sensor devices consisting of sensing, data processing, and communicating components, networked through wireless link [11]. In a typical application, a large number of such sensor nodes are deployed over an area with wireless communication capabilities between neighbouring nodes.

There is a number of works dealing with technical possibilities of sensor networks. Loke [11] lists a number of results, oriented on context-awareness of sensors and sensor networks. The idea behind is, that if sensors could know more about their own context, then they could adapt their behaviour and function only when needed and to the extent adequate to the current circumstances. This aspect can be important also for power consumption by the sensor. A lot of work has been done by [12], [13], [14], or [15], an interesting yet a bit older survey was written by Akyildiz et al. [3], but there is also a more recent survey [2].

3.2. Large-Scale Environmental Applications

Among a number of recent interesting environmental applications, we can mention the FieldServer Project [16], and the Live E! Project [17].

The FieldServer Project is oriented on development and networked applications of so-called Field Servers. A Field Server [16] is a wireless sensor network that will enhance the monitoring of environmental factors by allowing sensing nodes to be located at precise locations in fields, reducing overhead installation costs, and allowing for real-time data collection. In Japan, Field Servers were developed for applications at farms. They produce real-time images for security guards, and environmental data for farming. Scientists such as agronomists, physiologists and ecologists can exploit high-resolution real-time images in order to react on any specific situation that deserves or requires some intervention in the environment. Many types of Field Servers have been developed up to now.

The Live E! Project [17] is an open research consortium to explore the platform to share the digital information related to the living environment. Using the low cost weather sensor nodes with Internet connectivity, a nationwide sensor network was deployed [17]. The network has accommodated more than 100 stations. The application of this weather station network is intended for disaster protection/reduction/recovery and also as educational material for students.

According to [18], watershed management administers water resources within a watershed for different water users. The ultimate purpose of watershed management plan is to maximize the profits of different users meanwhile reducing the possible conflicts that might occur between them. Watershed management can be very efficiently modelled using multi-agent systems, nevertheless, there is just a few works taking into account also catastrophic situations (see, e.g., [19]).

Cardell-Oliver and her colleagues [12] proposed a novel reactive soil moisture sensor network that reacts to rain storms in such a way, that frequent soil moisture readings were collected during rain (approx. every 10 minutes), but less frequent readings (once a day) were collected when it is not raining. The network includes a node with a tipping bucket rain gauge sensor and, in another part of the landscape, a group of nodes with soil moisture sensors. The node monitoring rain is separated from the nodes monitoring soil moisture, and yet these nodes need to share information, whilst minimizing the time spent sending, receiving and listening to messages.

Some attempts to apply the Ambient Intelligence approaches to disaster management in general are described, e.g., in [20], where an architecture is proposed aiming to help in decision-making processes in disaster management. Here, several different environments are considered, namely a smart house, an airport and a paramedics unit doing assessing a victim of a nuclear disaster.

One of the most significant drivers for wireless sensor network research is without any doubts environmental monitoring. Its potential will not only enable scientists to measure properties that have not previously been observable, but also by ubiquitous monitoring the environment and supplying the related data to relevant supervising bodies they can create a basis of early warning systems for various environmental disastrous situations and their management. As it is in [21] pointed out, the relatively low cost of the wireless sensor networks devices allow the installation of a dense population of nodes that can adequately represent the variability present in the environment. They can provide various risk assessment information, like for example alerting farmers at the onset of frost damage. Wireless sensor networks based fire surveillance systems were designed and implemented, as well. They can measure temperature and humidity, and detect smoke following by early warning information broadcasting [22]. Sensors are able to consider certain dynamic and static variables such as humidity, the type of fuel, slope of the land, the direction and the speed of the wind, smoke, etc. They also allow determining the direction and possible evolution of the flame front.

However, apart from other similarly serious environmental disasters, floods are responsible for the loss of precious lives and destruction of large amounts of property every year, especially in the poor and developing countries. A lot of effort has been put in developing systems which help to minimize the damage through early disaster predictions (see, e.g., [23]). On the other hand, as drought periods, opposite to floods, cause lot of damage every year as well [24], also this problem deserves highest effort. Interesting solutions to the problems can be found e.g. in [25], [26], or [27].

Some other interesting related applications can be found, e.g., in [28] and [29]. The first one is devoted to assist workers in a coal mine in China, contributing to the higher security of their work. The second one describes an interesting case of a wireless sensor network supporting the safety of geophysicists working near a living volcano. A wireless sensor network was deployed to monitor eruptions at Tungurahua volcano, located in central Ecuador. This single hop network is constituted by five sensor nodes where three of them are equipped with a specially constructed microphone to monitor infrasonic signals originated by volcanic eruptions. The data collected by the sensors are sent to a local sink and then relayed over radio links to a computer located nine kilometres away.

In SensorScope project [15], two networks were deployed. The first network was installed in Wannengrat (Kanton Schwyz, Switzerland) in order to study environmental processes involving snow. The second network was installed on a glacier in the canton Valais, Switzerland, to measure air temperature, air humidity, surface temperature, wind direction and speed, precipitation and solar radiation. Seven nodes were used in the first deployment and sixteen nodes in the second.

The sensing nodes and the sink node uses TinyOS operating system. A multi-hop network wass used to support communications between the sink node and the sensing nodes. Sensing stations regularly transmit collected data (e.g., wind speed and direction) to a sink, which uses a gateway to relay the data to a server. Data is published on a real-time Google Maps-based web interface and on Microsoft's SensorMap website.

A very interesting and to our issues relevant paper was published by Vescoukis and others [30]. It was motivated by the fact, that there is a great increase of natural disasters (e.g., forest fires, flooding, landslides) which has stimulated a great research interest in developing smart and intelligent Environmental Information Management (EIM) Systems. These systems should be able to collect, process, visualize and interpret geospatial data and workflows of added-value applications so as to support decision making in case of emergency. It is quite clear that natural disasters pose a great threat to people's lives and their properties while they present a negative impact to the economies. In [30] a novel Service Oriented Information System is proposed that seems to be proper for Environmental Information Management, as well as for planning and decision support in case of emergency. The proposed architecture was designed in close collaboration with real world stakeholders in civil protection and environmental crisis management, and has been implemented as a real system, with applications in forest fire crisis management.

3.3. Outdoor Activities Support

In order to support a person's activities outdoor, her geographic location must be identified as an important contextual information that can be used in a variety of scenarios like disaster relief, directional assistance, context-based advertisements, or early warning of the particular person is some potentially dangerous situations. GPS provides accurate localization outdoors, although is not very useful inside buildings. Outdoor to indoor and vice versa activities localization was investigated e.g. in [31] by a coarse indoor localization approach exploiting the ubiquity of smart phones with embedded sensors.

Some our recent results in this area can be found also in [8], [9], [10], or [32].

Outdoor acting person's support should provide relevant and reliable information to users often engaged in other activities and not aware of some hazardous situations that he or she could possibly encounter. There are only a small number of attempts to solve the related dangerous situations that can be very briefly described using the following scenario:

A user appears in a natural environment performing her/his working mission, a kind of leisure time activity (hiking tour, mountaineering, cycling, etc.), or because of being an inhabitant of the area. A sudden catastrophic situation (storm, flash flood, debris flow, etc. could put the person in a risky, if not a life endangering situation. A federated wireless sensor network is ubiquitously monitoring the area and estimating the possible appearance of a dangerous situation. If necessary, the network will proactively broadcast an early warning message to the user, offering her/him related navigation services supporting escape from the dangerous situation.

In the literature, there is only a few works oriented on a kind of a service to the potentially endangered persons in a natural environment; however, this service is never such complex as in our scenario.

For instance, there are some attempts of preventing children from potentially dangerous situations in an urban environment. Probably the first ubiquitous system to assist the outdoor safety care of the schools kids in the real world is described in [33]. The research described there was focused on designing a ubiquitous kid's safety care system capable to dynamically detect possible dangerous situations in school routes and promptly give advices to kids and/or their parents in order to avoid or prevent from some possible dangers. To detect the dangerous situations, it is essential to get enough contexts of real environments in kids' surroundings. This is based on two basic assumptions: (1) a big number of sensors, RFIDs, tags and other information acquisition devices are pervasively distributed somewhere in and near school routes, and (2) a kids should carry or wear some devices that can get surrounding context data from the above pervasive devices.

A number of papers are devoted to various solutions for tourist assistance, mainly oriented on context-aware tourist navigation on their routes. The usual approach (see, e.g. [34] or [35]) is in deployment of intelligent agents, which collectively determine the user context and retrieve and assemble a kind of simple information up to multi-media presentations that are wirelessly transmitted and displayed on a Personal Digital Assistant (PDA). However, these tourism oriented applications are usually deployed for the navigational purposes, without having capabilities of warning the user from potentially dangerous situations that can appear during their routes.

4. Possible Agent-Based Solutions

Ambient intelligence environments may be considered as strongly related with multi-agent systems in that they can be adequately modelled using multi-agent systems of various types.

The organizational model *Aalaadin* [36] has been quite often used when speaking about participative water management support. The core concepts of the *Aalaadin* are agent, group and role [37]:

- An agent is defined as an active communicating entity, no constraints other than those triggered by the ability to play a role or not.
- A group is defined as a set of agents.
- A role is defined as an abstract representation of an agent function, service or identification within a group. The role encapsulates the way an agent should act within a group. Roles are local to groups.

According to [37] an agent can simultaneously play different roles in different groups, i.e. groups can freely overlap. An agent can enter or leave groups by acquiring or resigning a role, that is, groups are dynamic structures. Groups represent organizational levels and roles represent functions within these levels; through the roles it is handling, an entity gathers information from the different processes it is involved in without concern about eventual scale or time heterogeneity of these processes.

If we adopt this approach further on, we get a potential of using ambient intelligence concepts based on multi-agent models, usable for enhancing e.g. a river watershed by various AmI artefacts capable of ubiquitous communication and helping intelligently to manage the watershed.

Based on ideas presented by Iqbal and others in [1], we can think about Large-scale Ambient Intelligence as a large set of geographically widely distributed intelligent sensor resources with the main purpose of increasing significantly intelligence of various segments of real nature. By a smart sensor resource we shall mean a kind of ambient artefact, namely a combination of an advanced sensor with ubiquitously computing and communicating processor integrated with the sensor. They purpose will be given by their main tasks, so that a number of their specific types could be possible. Let us mention some examples:

- smart water level guards;
- smart soil humidity sensors;
- smart forest fires guards;
- smart wind velocity sensors;
- and a couple of others.

Speaking about guards, we shall mean special kind of intelligent sensors applicable namely for early warning purposes in such cases, when e.g. the water level increase achieves some given gradient, or when temperature in a segment of a forest overreached the given level. In such a case the intelligent sensor resource will communicate a kind of alarm which will be propagated through whole sensor network and immediately elaborated further on by the responsible parts of the network.

Multi-agent architectures seem to be applicable here, as it is common in the case of large networks of sensors. We can tract various types of intelligent sensors and guards as agents with appropriate level of intelligence, recent dispatchers or even dispatching centres can be modelled as supervising agents (e.g., river basin management dispatching centres or fire brigades dispatching centres, etc.).

Certainly we can imagine a number of various kinds of guards and sensors. Let us present some examples, which are technologically feasible and frequently used in large-scale wireless sensor networks:

- *water level guards*, monitoring surface water level, or even groundwater level and watching over potentially dangerous or at least unusual situations.
- *water quality guards*, monitoring surface and groundwater quality and watching over possible contaminations or pollutions.
- *air pollution guards*, monitoring air quality, watching over possible pollutions.
- *wind velocity sensors*, monitoring wind velocity and watching over potentially dangerous situations.
- *soil moisture sensors*, measuring level of soil humidity, e.g. in forests, or in a river watershed, aiming at monitoring the degree up to which is the land segment saturated by water, and measuring the capacity of further possible saturation.

Of course, other kinds of intelligent sensors integrating ubiquitous monitoring (computing) of measured parameters with ubiquitous communication with other sensors – agents – in the area are possible as well.

We believe that the main application area for large-scale ambient intelligence will be any kind of prevention, connected with early warning facilities. Such areas as fire prevention, water floods prevention and early warning, or accident prevention in urban traffic could be clear candidates.

In water floods prevention area we can imagine the usage of the following agents:

- water level monitoring agents;
- land segments saturation (moisture) guards;
- water reservoir handlers;
- supervising agents.

The concept of our solution to the problem described in the second part of this paper consists of the following steps:

Establishing a large-scale wireless sensor network, consisting of already installed water level guards, completed by a number of sensor subnetworks, composed from soil moisture guards, situated in those land segments that are already known as critical from the soil saturation point of view.

The established large scale wireless sensor network will be embedded in a multi-agent architecture, where the particular sensor subnetworks of various types will play roles of group of agents in the multi-agent architecture.

The special roles are assigned to manipulating agents, as are, e.g., water reservoir Nyrsko handlers, or three river weirs manipulators.

The whole system is designed as hierarchical, as there is a number of concentrators, that is agents collecting the data as well as messages from the groups of agents defined in the step 2. These concentrators then communicate mutually as well as with the supervisor that is an agent with the task of evaluating the data as well as messages, and after judging the level of their importance it will start a respective action, or a whole sequence of actions, adequate to the situation appraised.

The implementation of the just described concept of the proposed solution is actually only in its early stages. However possible benefits of the proposed solution can be seen in:

- early warning possibilities;
- evacuation optimization;

- logistical planning;
- watershed manipulation optimization.

A number of other related ideas and solutions can be found also in [38], [39], [40], [41] or [42], among many others. Actually, this is a rather living and promising area of research.

5. Conclusions

In the paper, after an analysis of various recently used approaches, we presented a proposal of using multi-agent based and with ambient intelligence technologies enhanced application of an environmental wireless sensor network in the scope of water management. Except traditional centralized architecture of single reasoning agent (computing counterpart of human watershed manager), it is possible to use systems of reasoning agents, or to apply multi-agent simulations for verifying hypotheses about the next course of processes in the river basin. Partial implementations of multi-agent applications are expected to simplify communication with domain experts during the process of modelling their knowledge, identifying their needs and summarizing requirements on final application functioning. Further applications of the *Large-scale Ambient Intelligence* can be foreseen in various environmental areas as prevention of certain catastrophic situations, as water or air pollution, or in various agricultural fields.

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