

# Environmental Intelligence Based on Advanced Sensor Networks

D. Stipanicev, Lj. Bodrozic and M. Stula

*Department for Modelling and Intelligent Systems*

University of Split - Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture

R.Boskovic bb, 21000 SPLIT, Croatia

Phone: (385) 21-305 813 Fax: (385) 21-463 877 E-mail: [dstip@fesb.hr](mailto:dstip@fesb.hr)

**Keywords: environmental intelligence, sensor network, observer network, forest fire detection**

**Abstract – By appropriate integration of advanced ICT systems in an environment, in a way that those highly technological systems become almost its integral part, it is possible to provide additional environment features. Those features are primarily self-monitoring and self-protection, giving the environment rudimentary intelligence and possibility, to operate not only by reaction, but also to operate proactively, having in "mind" its self-protection.**

**In such a way the environment becomes the intelligent environment or more accurately the intelligent self-monitoring, self-protecting and self-aware environment that reacts on changes and in real time alarms humans responsible for appropriate environment protection actions which will prevent environment further degradation.**

**The paper describes overall architecture of such intelligent environment based on advanced sensor network called the observer network. As an example the system architecture of the forest fire monitoring system is discussed.**

## 1. INTRODUCTION

Today environmental protection is of a vital interest in almost all countries. Severe environmental changes and meteorological abnormalities are caused by intensive technological development, so necessity for efficient environmental protection is one of the most important civilization tasks. Efficient environmental protection based on preventive, or at least on 'just-in-time' actions, could be realized only if we have appropriate environmental diagnostic system, or, more precisely, the real-time environmental monitoring system capable to collect and analyze all information relevant to environmental state. Environmental Information Systems (EIS) and Environmental Monitoring Information System (EMIS) are intensive research areas, partially due to these efforts and partially due to the IC technology development providing new environmental monitoring methodologies and procedures. Sensor network, based on automatic ground-based monitoring stations, enables more flexible real-time environment monitoring, diagnostics and finally protection, or at least prevention of further serious degradations by an appropriate human intervention and action.

Integrating intelligent sensor units in the environment itself, the level of environment protection could be substantially raised, giving the environment a lot of new intelligent features. These features are primarily self-monitoring and self-protection and the possibility of, not only reactive, but also proactive reaction maximizing the level of its self - protection. The environment becomes an intelligent environment, or more precisely a self-

monitoring and self-protecting environment, aware of its present state with possibility of automatic alarm rising if something happened. Raising alarms in early stages and good simulation scenarios could highly diminish the level of environmental degradation caused by ecology accidents.

To implement these features, it is necessary to work not only on the development of new sensor units and communication between them, but also on the development of new procedures and algorithms for environmental data collection, analysis and verification.

Our approach, discussed in this paper, is based on ideas of formal observer theory introduced in 1987. by Bennet, Hoffman and Prakash [1].

In the next chapter first we will discuss the concept of environmental intelligence related to the other researches connected with intelligent technologies and environment. The third chapter is dedicated to sensor networks and observer theory and the last one describes our case study – the forest fire environment protection based on the advanced sensor network.

## 2. INTELLIGENT ENVIRONMENT AND ENVIRONMENTAL INTELLIGENCE

Terms '*intelligent environment*' and '*environment intelligence*' are first of all used to describe the environment that is adapted to humans in an intelligent manner, or the environment that takes care of its own parameters with intention of reaching a specific goal [2], [3].

For example, the intelligent building, which has a goal to minimize its own energy consumption, maximizing humans comfort, or intelligent crossroad, with a goal to minimize the period of drivers waiting on traffic lights. In all those cases the term '*intelligent environment*' is primarily used to describe an ambient which adapts to its user needs and because of that the more appropriate term could be '*ambient intelligence (AmI)*', the term also used in a lot of papers discussing these topics [4]. Differing from homocentric systems of environmental intelligence, our approach is more close to research ideas of "Centre for Intelligent Environment Systems" [5]. Their research topics are "...*the application of artificial intelligence (AI) to problems affecting the natural environment...*" or more precisely "...*on the development of intelligent systems for the biological monitoring of river quality...*". Their tasks were primarily focused on using high technology in environment monitoring and we adopted that. The main idea is to integrate environmental monitoring systems into environment itself, giving it the ability to predict the potential degradation, on top of only sensing it. When

needed, the appropriate alarms could be activated, calling humans responsible for intervention in the case of environmental disaster. Using this approach, and, of course, if the human intervention is appropriate and effective, it is possible to minimize the damage caused by certain environmental disaster.

So, the term *environmental intelligence* in our context describes the environment self-protecting ability introduced by advanced sensor network integration into environment itself. The main task of advanced sensor network is the automated monitoring the environment, trying to recognize potential environmental hazards and disasters and to raise appropriate alarms automatically.

### 3. SENSOR NETWORKS AND OBSERVER NETWORKS

Sensor network technology is one of the key technologies for 21<sup>st</sup> century [6]. Generally speaking sensor network is a network consisting of spatially distributed autonomous devices using various sensors to cooperatively monitor physical or environmental conditions at different locations. Communication between sensing units in most cases is realized using wireless communication, so the name wireless sensor network (WSN) is also in use [7]. Today, there is a lot of potential sensor networks applications like environmental monitoring, building and structures monitoring, military sensing, physical security, traffic surveillance, video surveillance, distributed robotics and similar. Different sensor network architectures have been proposed, and in context of our case study we will concentrate on three layer architecture shown in Fig.1.

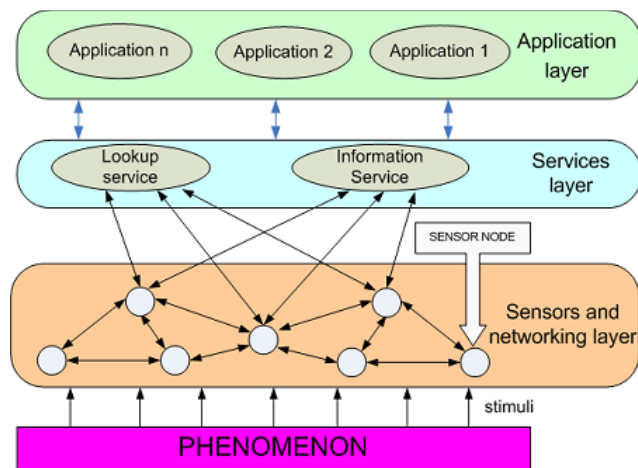


Fig. 1. Three layer architecture of a sensor network.

Such three layer architecture was proposed by EU Eyes project [8], but we have modified it to better suit our approach and our ideas.

The first layer is the *sensors and networking layer* which contains the sensor nodes and the network protocols. In most cases ad-hoc routing protocols are used particularly in the case of mobile nodes and dynamic change of topology, but if sensor nodes have fixed positions, any standard routing protocols could be used. Each sensor node consists of sensors, processor and

transmitter. Sensors respond to certain stimuli caused by monitoring phenomenon.

The second layer is the *services layer*. It contains services for supporting sensors layer. Two major services have been identified. The *lookup service* supports sensors administration and it is used in case of new sensor adding or removing, network reconfiguration or in case of sensors mobility. The *information service* deals with aspects of collecting data. This service is responsible for reliable and easy access to sensors data and their customization for third level applications. Services from the service layer could communicate with all sensor nodes either directly, or indirectly through certain sensor nodes called master nodes or the base nodes, but in both cases all services can communicate (either directly or indirectly) with each sensor node.

The third layer is the *application layer* where various applications could be built using services and sensor network.

Following the theory of knowledge engineering, the sensor and network layer could be treated as *data level*, services layer as *information layer* and application layer as *knowledge layer*. Sensors generate pure data, information layer transforms them to information and application level use those information to generate knowledge about observed phenomenon.

Our main area of interest are the service layer and the application layer, because advanced sensor network features could be implemented on those levels, but first we will introduce the formal definition of the observer.

In 1987 Bennet, Hoffman and Prakash [1] introduced an approach to a study of perception that attempted to be both rigorous and general. They proposed a new formal foundation – the observer. The *observer* is defined as a six-tuple

$$O = (X, Y, E, S, \pi, \eta) \quad (1)$$

where  $X$  and  $Y$  are measurable spaces,  $E$  and  $S$  are subsets of  $X$  and  $Y$  respectively,  $\pi$  measurable surjective function and  $\eta$  conclusion kernel. Space  $X$  is a *configuration space* of the observer and  $E$  is a *configuration event* of the observer. Space  $X$  is a formal representation of those possible states of affair over which the configuration event  $E$  of the observer is defined.  $Y$  is a *observation space* of the observer. Space  $Y$  is a formal representation of the premises available to the observer for making inferences about occurrences of  $E$ .  $S$  is the *observation event*. All and only points in  $S$  are premises of observer inferences which conclude that an instance of the configuration event  $E$  has occurred.  $\pi$  is a *perspective map*, the measurable surjective function from  $X$  to  $Y$  ( $\pi : X \rightarrow Y$ ) with  $\pi(E) = S$ .  $\eta$  is a *conclusion kernel* of the observer. For each point in the observation event  $s \in S$ ,  $\eta(s, \cdot)$  is a probability measure on  $E$  supported on  $(\pi^{-1}(s) \cap E)$ . This means that kernel  $\eta$  is a convenient way of assigning to every point of  $S$  a probability measure on  $E$ .

Now let us go back to sensor network architecture. Each sensor node  $se_i$  on sensors and networking layer has its corresponding virtual nodes in both services of services layer, and one virtual node at each application on the application layer.

Let us concentrate on information service only. Information service is responsible for data collecting and it has a set of virtual nodes arranged in triplets

$i_i=(dc_i,ssv_i,sdv_i)$ . Each triplet  $i_i$  of information service virtual nodes corresponds to its sensor node  $se_i$ . Virtual node  $dc_i$  is responsible for data collecting from sensor node, and  $ssv_i$  and  $sdv_i$  are responsible for sensor and data validation. The main task of  $ssv_i$  is sensor syntactic validation and the main task of  $sdv_i$  is the sensor data semantic validation. The syntactic validation tests sensor physical functionality and the semantic validation tests sensor data logical functionality.

Each application on application layer also has virtual nodes. Virtual node  $a_k$  at application layer could be connected with several virtual nodes at information service layer. Those information nodes form the set of information nodes  $I_k$  which correspond to application layer node  $a_k$ .

In the sense of definition (1) the pair  $(se_i, i_i)$  can be interpreted as the observer, but the observer is also the pair  $(a_k, I_k)$ . The first one is data - information level observer. We simply call this observer the **low-level observer** or **data observer**. The second one is information - knowledge level observer, simply called **high-level observer** or only **observer**. Fig.2 shows the new sensor network architecture which could be now treated as **observer network**.

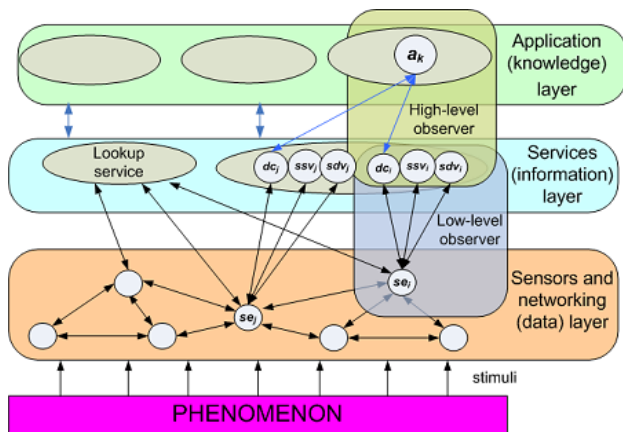


Fig. 1. Three layer architecture of the observer network.

#### 4. INTELLIGENT FOREST FIRE MONITORING SYSTEM

As a case study we will describe basic principles of intelligent forest fire monitoring system shortly called **iForesFire** designed and developed in our department. More details could be found on our Web site <http://iForestFire.fesb.hr>. Forest fires represent a constant threat to ecological systems, infrastructure and human lives. Croatia belongs to countries with enhanced summer forest fire risk particularly the Dalmatian coast and islands. Because of that a lot of efforts have been made in forest fire prevention and since 2003 we have intensively worked on development of intelligent forest fire monitoring system based on our ideas of the observer network. The system was successfully tested during 2005 and 2006 fire seasons on three experimental locations.

The monitoring phenomenon is the forest fire and stimuli are smoke caused by forest fire seen by video camera sensitive in visible spectra. Because of that, one type of our sensor nodes is selected to be CCD video camera connected to embedded processing unit and

communication device. We have used pan/tilt/zoom controlled video camera, embedded video Web server as a processing unit and WiFi wireless communication. Another type of sensors used in our system was mini meteorological station having embedded data Web server as a master sensor node and different meteorological sensors (temperature, humidity, wetness, atmospheric pressure, wind speed, wind direction, isolation) as sensor nodes. Fig.3 shows our experimental system during testing period in 2006.



Fig. 3. Monitoring unit and user interface of experimental intelligent forest fire monitoring system iForestFire.

Although both types of sensor nodes have been used in forest fire detection application on application level, we will here discuss here only video part.

Each video camera has its corresponding information service triplet  $i_i = (dc_i, ssv_i, sdv_i)$ , responsible for video capturing from certain camera positioned in appropriate preset position every  $x$  seconds ( $dc_i$ ), video camera physical presence validation ( $ssv_i$ ) and video camera semantic validation ( $sdv_i$ ). Semantic validation is for example automatic checking is the present preset position the right one, because for the forest fire smoke detection it is important to have camera in appropriate preset position. For this low-level or data observer its appropriate configuration event  $E$  according to equation (1) is the 3-D space (with or without smoke caused by forest fire). Observation event  $S$  is the image captured by video camera and perspective map (function  $\pi$ ) is transformation of 3-D space to 2-D digital image. Low-level observer is responsible for preparation of digital image which correspond to certain camera preset position.

Task of the high-level observer is not only the forest fire detection, but also the determination of forest fire position in 3-D space. Because of that its internal structure is not so simple and it includes several types of observers arranged in groups. Fig. 4 shows schematically this structure. Each group of internal observers is connected with one low - level observer, in reality with one monitoring camera.

One group of internal observers is divided into two levels. On the first level there are **image fire observers (IFO)**. All of them correspond to one low-level observer. This means that all of them have the same configuration event  $E$  and that is the digital image created by the low level observer of one camera.

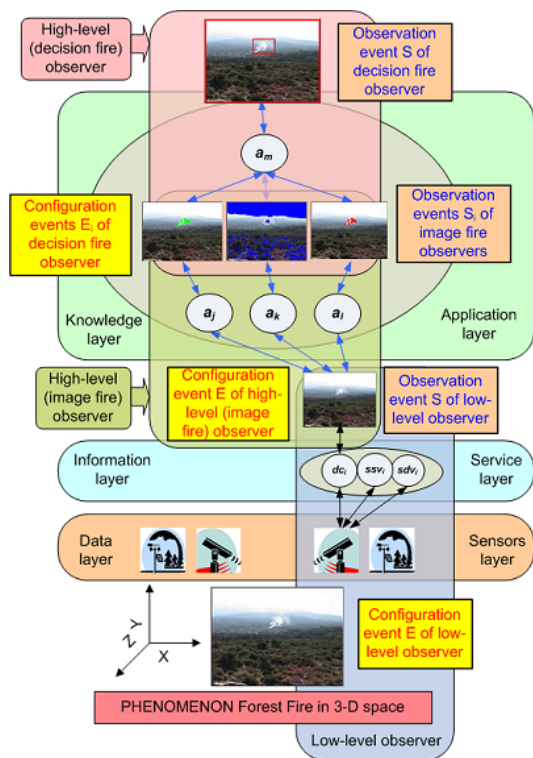


Fig. 4. Forest fire detection system seen as an observer network.

All of them also have the same observation space  $Y$ , but not the same observation event  $S$ . Their observation events are digital images similar to configuration event digital image  $E$ , but with forest fire smoke pixels visibly marked. The difference between them is because each of them have different perspective map  $\pi$ . Perspective map  $\pi$  transforms input digital image  $E$  into output image  $S$  ( $S = \pi(E)$ ) where pixels which belong to forest fire smoke are visibly marked. Practically these perspective maps ( $\pi_1, \pi_2, \dots, \pi_n$ ) in real application correspond to various image understanding procedures based on advanced image analysis methods and their result is set of images ( $S_1, S_2, \dots, S_n$ ) where forest fire smoke pixels are segmented.

On the second level there is only one observer called **decision fire observer (DFO)**. Configuration event of this observer are all observation events ( $S_1, S_2, \dots, S_n$ ) of image fire observers. Its observation event is decision about fire detection with degree of confidence and fire location estimated from 2-D image. The second high-level observer group is connected with another monitoring unit, the third with the third and so on. If few units cover the same fire event, better degree of confidence and better estimation about fire location is provided.

Discussion about forest fire observer verification and its **conclusion kernel** which includes analysis of the fire detection algorithm relative efficiency is a separate topic and it will be discussed in our next papers. At the end let us also mention that the software organization of intelligent forest fire monitoring iForestFire system is completely based on agent architecture [9] which nicely fits in the observer network structure.

## 5. CONCLUSION

In order to better protect the environment the idea of environmental intelligence is described in a sense that the term means the environment self-protecting ability

introduced by advanced sensor network integrated into environment itself. The main task of advanced sensor network is to automatically monitor the environment, trying to recognize potential environmental hazards and disasters and then automatically raise appropriate alarms.

Our case study was forest fire protection, because Croatian coast and islands have quite enhanced summer forest fire risk. The intelligent forest fire monitoring system called **iForestFire** was designed and successfully used during 2005 and 2006 fire seasons.

The layer architecture of iForestFire is a newly introduced idea of the observer network. Observer network is defined as a more advanced sensor network described using formal theory of perception and a notation of the observer. In software part our intelligent forest fire monitoring system is completely based on agent architecture which nicely fits to observer network structure. The aim of this paper was primarily to describe system architecture based on observer network ideas. Topics concerning fire detection algorithms, its relative efficiency and system implementation (cost, coverage, redundancy) will be discussed in our next papers.

## ACKNOWLEDGEMENTS

This work was supported by the Ministry of Science, Education and Sport of Republic Croatia under Grant 023-00232005-2003 "AgISEco - Agent-based intelligent environmental monitoring and protection systems".

## REFERENCES

- [1] B.M.Benett, D.D.Hoffman and C.Prakashi, "Observer Mechanics – A Formal Theory of Perception", Academic Press Inc., Public Domain, 1989. <http://www.cogsci.uci.edu/personnel/hoffman/ompref.html>
- [2] S.Mann, "Reconfigured Self as Basis for Humanistic Intelligence", *Closing Kaynot Speech at USENIX 98, New Orleans, 1998.*, <http://wearcam.org/usenix98/>
- [3] "Intelligent Environment Resource Pages", <http://research.microsoft.com/ierp/>
- [4] "ISTAG – Scenarios for Ambient Intelligence in 2010", *ISTAG – Information Society Technologies Advisory Group (EC) - Final Report*, Feb 2001, <http://ftp.cordis.europa.eu/pub/ist/docs/istagscenarios2010.pdf>
- [5] "Centre for Intelligent Environmental Systems", <http://www.cies.staffs.ac.uk/>
- [6] C.Chong and S.Kumar "Sensor Networks: Evolution, Opportunities and Challenges", *Proceedings of the IEEE*, Vol.91, No.8, Aug. 2003, pp. 1247 – 1256
- [7] K.Römer, F.Mattern "The Design Space of Wireless Sensor Networks", *IEEE Wireless Communications*, Vol.11, No.6, Dec. 2004, pp. 54 – 61
- [8] "EYES – Energy Efficient Sensor Network", EU Research Project, 2002 – 2005, <http://www.eyes.eu.org>
- [9] Lj.Bodrozic, D.Stipanicev, M.Stula, "Agent Based Data Collecting in Forest Fire Monitoring System", *Proc. of 2006. Int. Conf. SofiCOM 2006*, Split, Dubrovnik, Sept. 29.-Oct.1. 2006