HAZARDOUS – FLOOD EARLY WARNING SYSTEM

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Keywords

Urban flash flood, Early warning system, system integration, ontologies, GIS, SCADA

Abstract

This paper shows the preliminary results of Hazardous research program, still in progress and supported by "POR Sicilia 2000-2006 Misura 3.14". The coordinator of the project is Proteo S.p.A., an Italian SME specialized in developing environmental ICT solutions; the partners are:_the University of Palermo, the Civil Protection of Catania and Palermo towns, the Campania Region Fire Department, Sicily Hydrographic Office. The main aim of Hazardous is the design of an urban flash flood early warning system. In particular this paper describes the approach used to integrate the GIS component with the heterogeneous remote sensing system and with the real time applied model. This target has been achieved by providing a sharable knowledge base, based on ontological development and integration, to satisfy the need to master and integrate all the software system components that are SCADA (Supervisory Control and Acquisition Systems) / GIS (Geographical Information Systems) / DSS (Decision Support Systems). Two prototypes of the Hazardous system will be implemented and located in Catania and Palermo: the two biggest towns of Sicily.

Introduction

In order to successfully manage natural hazards, the need is to identify, assess and control various factors that contribute to harm in the supervised area. These factors depend on a large set of heterogeneous information, which is often owned by different entities, and which ranges from sensor data, communication vectors, demographic data, land use data, available transportation etc.. All this information needs to be integrated to allow seamless use and consistent management, and then they need to be processed and reliably-and quickly communicated. In order to achieve this goal the challenge is to move from traditional centralized control systems to a distributed heterogeneous array of devices, with complex logical and physical interactions (Murray et al., 2003). The side effect of such a novel approach is the growing need of tools, which are able to guarantee the coherence and consistency of data and services distributed among the remote locations. Commercial Supervisory Systems provide monitoring and automatic protection functions, but they are not usually able to provide early warning detection, and in-depth warning diagnosis. A key issue in safety critical systems (EC, 2000) is warning diagnostics, as they are early warning systems of natural hazards. Therefore advanced supervision methods are necessary in order to overcome the supervision methods based on the classical limit value (Isermann, 2004). Several different innovative approaches and methods for supervision, early warning, fault detection and diagnosis have been recently developed (Isermann, 1997). Each method is specialized to solve a specific kind of problem, and it is based on different knowledge bases of the supervised system. As a consequence, in order to cover the needs of a safety critical application, the optimal strategy is based on a framework of integrated use of different

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methods (Ploix et. al., 2003). Furthermore the role of decision making in the field of widespread systems control is becoming an increasingly key item. This decision making includes high levels of abstract reasoning based on soft computing and Artificial Intelligence (AI) (Murray et al., 2003). Since each of these different approaches and methods is based on its own knowledge base, the main problem to overcome is to provide a holistic and consistent conceptual model of the supervised system.

The conceptual model would represent the result of the integration among all the different knowledge bases used to carry out the supervisory system. The main goal of the integration process is to develop a conceptual model that supports an interdisciplinary approach for the management of the whole flash flood early warning system. Experts from different disciplines involved in the flash flood management, as well as the different components of the distributed supervisory system as software agents and application systems, as SCADA, GIS, software simulation models, DSS, require access to the same data, but for different purposes. As a consequence, they can overlap different kind of structures, meanings and relations to the same data. Ontologies have been developed in AI to facilitate knowledge sharing and reuse. In general ontologies provide a common understanding of a domain and an explicit conceptualization that describes the semantics of the data (Gruber, 1993). Moreover ontologies are defined as a formal specification of a shared conceptualization, generally based on first order logic (Artale et al., 2004), that must be machine readable (Studer, 1998). Hazardous deals with the design of a Rule Based Expert System (RBES) able to provide on line early warning of flash flood consequences, fault detection and diagnosis of the early warning system, contributing a machine readable integrated conceptual model of the whole system.

In this research programme techniques are being developed for the automation of data analysis and interpretation, so that the potential of data sources is fully realised. These tools will maximize the benefit of available data for informing early warning systems, since the capability to get, in real time, knowledge from data is essential for the efficient and effective management of flash floods to protect public health. This goal will be achieved through the development and application of a novel artificial neural network named Cellular Neural Network (CNN) (Chua, 1988) that is able to provide real time modelling of physical phenomena represented by Partial Differential Equations (PDE).

The CNN paradigm can be used to compute the transience of PDE after spatial discretization. The solution of these equations requires spatial discretization with an appropriate numerical integration method to reduce the PDE to a set of Ordinary Differential Equations (ODE). This set of ODEs can be mapped in a CNN array and its transience gives the solution (Szolgay, 1993). By using CNN, faster computation of PDE can be achieved; this huge computing power may be useful when real time solutions of PDEs are required. This work will investigate a CNN architecture able to map the 2D spatial numerical integration schema for preserving the qualitative properties of PDEs.

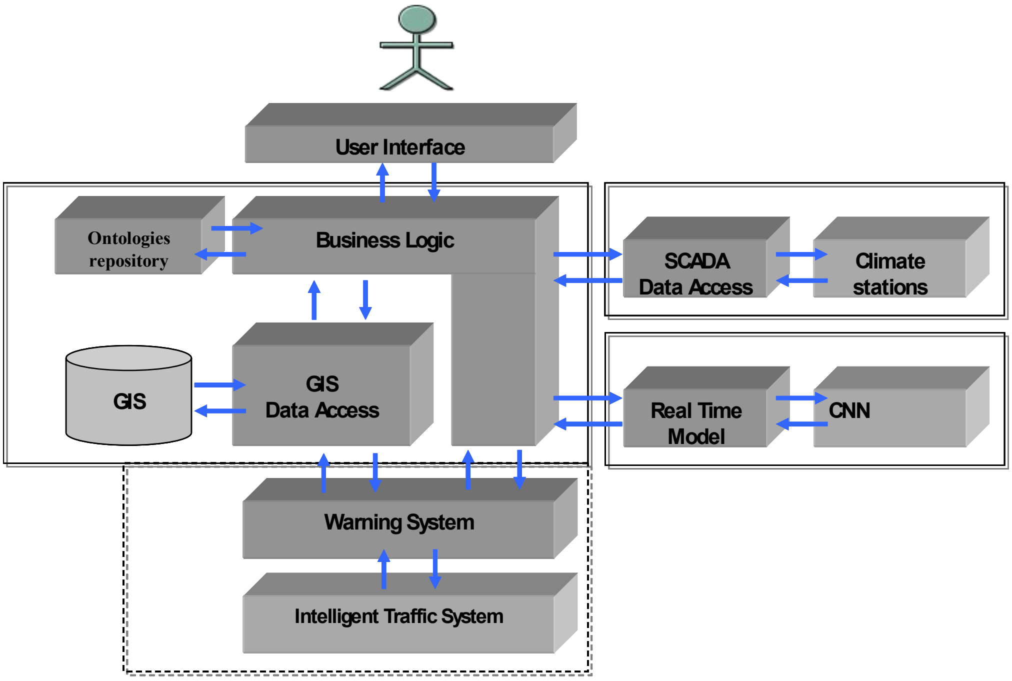
Hazardous architecture

The main goal of Hazardous platform is urban flash flood nowcasting and warning. After the hazard has been recognized, because of the short time frame available to forward the warning, Hazardous exchanges information directly with the people affected by the flood. The main communication channel, chosen by Hazardous to warn the people in danger, is a network of electronic signs suitably distributed in the urban area.

Hazardous platform masters and integrates an heterogeneous system of climatic and hydrometric sensor networks, owned by independent meteorological services. The real time processing of rain and flow level gauge data allows Hazardous system first to track the storms and thus to nowcast flash floods, and then to provide an early warning about the imminent hazard.

Main Hazardous components are: the GIS, the Warning System integrated with the Intelligent Traffic System (ITS), the distributed SCADA, which manages the Remote Sensing Systems, the Cellular Neural Network module (CNN), and the User Interface module (UI). All the components are loosely coupled via Web Services, by using a middleware architecture that in the following figure is represented by the Business Logic layer.

Fig 1 – Hazardous architecture

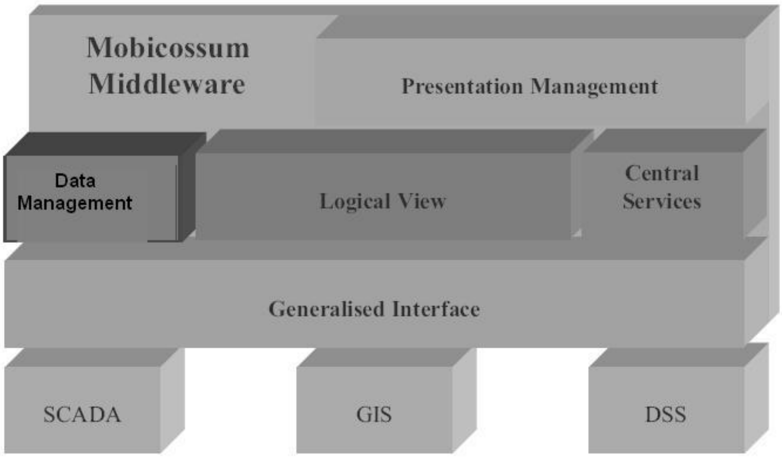


Web Services are simply software applications that can be integrated one to each other, by using open Internet standards, HTTP and XML. Web Services offer an infrastructure to easily integrate multi platform distributed application, because they are URL (Universal Resource Locator) addressable resources that return information to clients who want to use it. One important Web Services feature is the fact that the Web Services represent black-box functionality that can be reused whatever service is implemented. Web Services provide well-defined interfaces, called contracts, which describe the services provided. Developers can assemble distributed applications using a combination of remote services, local services, as well as custom code.

The middleware architecture used to integrate the Hazardous components is based on a previous research project named Mobicossum (Advance Mobile Computing Software System for Utilities Management) (Cavalieri et al, 2004a). Mobicossum platform offers high level services to support the interaction between mobile operators and a pervasive system of distributed elaboration sources as an array of heterogeneous SCADA Systems, Geographical Information Systems, and Decision Support Systems.

As shown in figure 2, the Generalized Interface (GI) (Cavalieri et al, 2004b) is placed at the lowest level in order to provide basic access to the SCADA, GIS and DSS applications. The GI offers a unique set of services, internally mapped to the real services offered by each set of SCADA, GIS and DSS applications. The set of services made available by the GI can be directly handed by a user, or may be accessed by the other components of Mobicossum Middleware. For this reason, the other components are placed at a higher level. The client (mobile user) interface is represented by the Presentation Management, placed at the top of the Architecture.

Fig 2 – Mobicossum architecture



The following section briefly explains how Mobicossum platform has been extended to include semantic integration capabilities in order to ensure flash flood management.

Semantic integration of Hazardous software components via ontologies.

A key role in the Mobiccossum architecture is the Data Management (DM) component (figure 2). In fact DM ensures the cooperation among heterogeneous information systems. Successful integration among heterogeneous information systems needs more than physical connectivity; firstly it needs to know what information is needed to be accessed, determining where they are and how they can be acquired, and secondly it needs to interpret that information within the appropriate context. Mobicossum DM answers the first requirements, the DM derives from the need of data brokerage inside Mobicossum. Mobicossum users could have no idea about the location of information they need and about the application that maintains the information. For this reason data brokerage is aimed to identify real applications containing data requested by the user and to identify real tag (ID) of these data inside each real application, in order to read/write each datum. According to the internal architecture of Mobicossum, DM has the task to perform data brokering, as explained in the following. The real application (SCADA, GIS, DSS) exports its methods by using Web Services. Each application may have one or more Web Services, because each application's Web Service is able to perform specific operations. An Application Identifier (ApplicationID) is assigned to each real application. In Mobicossum environment this parameter must be unique and it is assigned to the real application, in the moment of the integration of the real application into Mobicossum. DM supports reliable data brokering providing high level services as the following functions:

- GetApplicationIDbyModelName
- GetApplicationIDbyPlant
- GetApplicationIDbyUserCoordinate
- GetVarsIDbyDeviceType
- GetVarsIDbyUserCoordinate

In the Hazardous project DM capabilities have been extended to ensure semantic interpretation of heterogeneous software services and data, and to ensure their reconciliation in case of semantic conflict. The designed ontology is able to manage several kinds of relations among the spatial entities and the spatial process models, used to simulate dynamic urban floods.

In Hazardous spatial process models are used in order to track the storm motion and to simulate the evolution of shallow flows. For these two different kind of spatial process models both Eulerian and Lagrangian conceptual views have been used. Storm movement has been described as a Lagrangian motion on an urban area; on the contrary water runoff caused by the storm has been modelled as an Eulerian change over the time.

Four main kind of relations, among spatial entities, and spatial process models, have been taken into account (Brown, 2004):

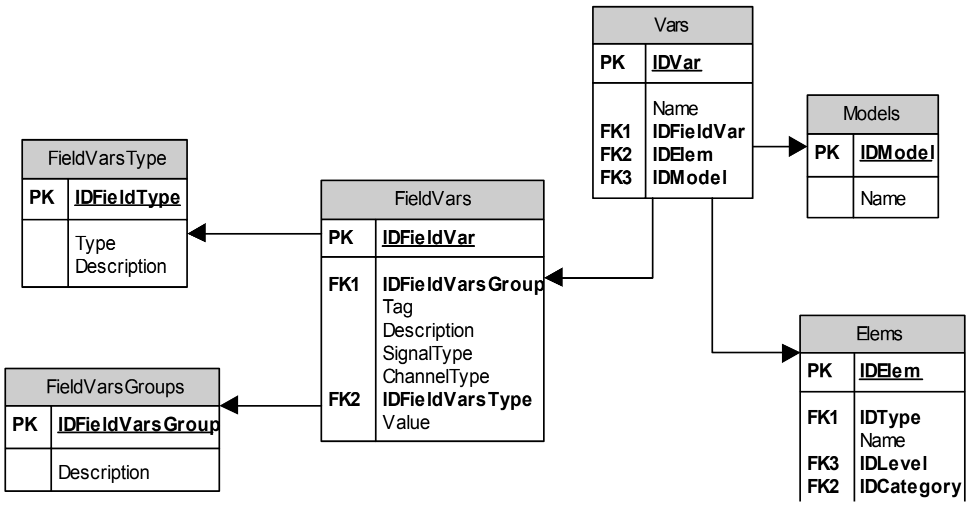
- *Identity relationships*: a spatial features associated with agents, which are used to simulate a spatial process over the time, can move or change, and attributes of features associated with agents can change.
- *Causal relationships*: agents have the ability to take actions that affect spatial features and/or their attributes, even if there is no identity association between the agent and the spatial features it is acting on
- *Temporal relationships*: the actions of the agents and the updating of attributes or locations of features can be handled using synchronous or asynchronous approaches.
- *Topological relationships*: movement of spatial features can require basic information about the physical world or spatial relationships between features.

The ontology has been designed modelling the relation among four main kinds of concepts:

- *Models*: set of spatial process models used in the system.
- *Elements*: set of objects represented in the system. Each element belongs to one or more models.
- *Vars*: set of time varying attributes. For instance, SCADA variables are represented in this class. Each Var is ever linked with an element and a model, but not vice versa.
- *Events*: set of events which can happen; each event impacts on one or more elements, and an element can trigger events.

The following figure shows the Vars ontology, and its relations with other entities as Models and Elements.

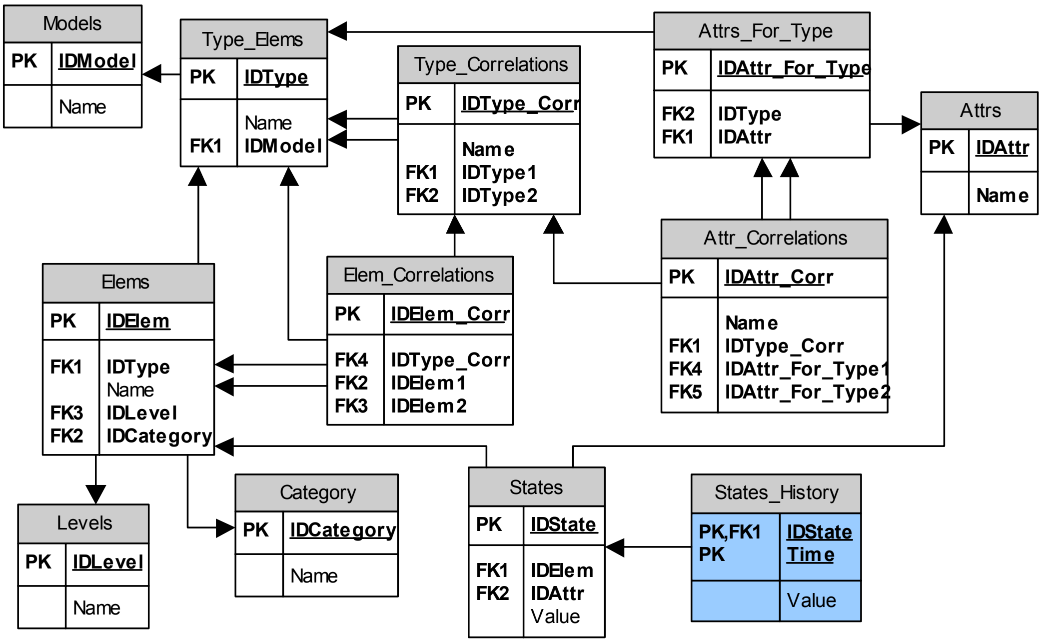
Fig 3 – Ontology of SCADA variables



In the following figure (figure 4) the relationship between Elements and Models is explained. It is of interest to note that the same object could be represented, inside different kinds of models, by different elements, and that these distinct elements could share some attributes.

For instance a street could be represented in a traffic model as a transportation means, used by road haulage or by pedestrian traffic; the same street, during a flood, could be represented as an escape route or alternatively an open channel in which the water level and/or its velocity is temporarily too high.

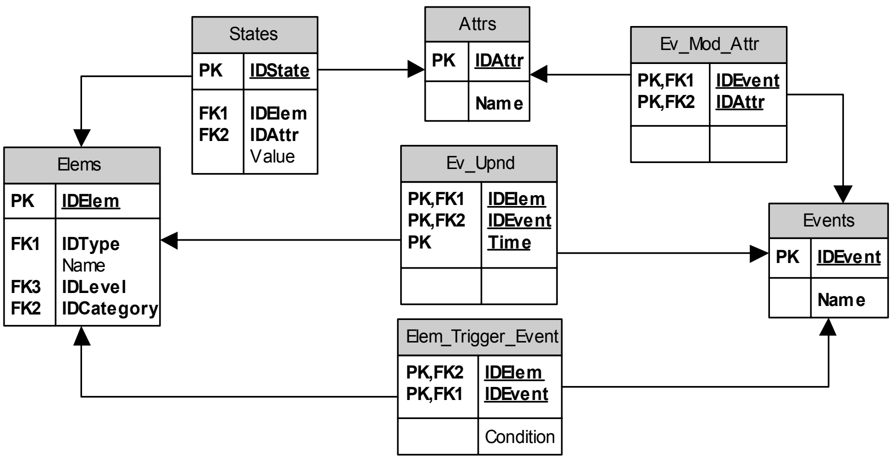
Fig 4 – Relationship between Models and Elements



The States History table (figure 4) permits to manage states that change over the time and to simulate scenarios in extended time.

Finally the last designed relationship is between Elements and Events. In this case it has been modelled how an element can trigger an event, or alternatively an event can change the status of an element. The relationship between Elements and Events has been shown in the following figure (figure 5).

Fig 5 – Relationship between Elements and Events



The conceptual model, briefly described above, has been implemented by using OWL (Ontology Web Language) and embedded in the Mobicossum DM.

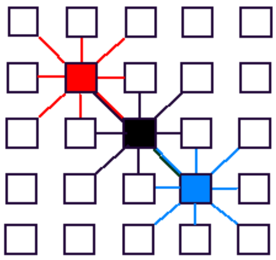
By this way Hazardous Business Logic (figure 1) is able to automatically check, by using in real time a RBES as reasonor, the reliability of the processed data and the consistency of the knowledge derived from these data.

Modelling flash flood by CNN

The hydraulic simulations, based on novel real time simplified numerical models, allow on-line early analysis of risks related to flash flood events, based on the real time SCADA database. By this way the simulation results, as well as the input GIS and SCADA data, are used by the Decision Support System in order to provide the emergency manager and the operations staff data necessary to identify an event, locate the extent and the potential danger, and prepared to react in a proper and timely way. For this purpose, in Hazardous project, Cellular Neural Networks are used to model in real time urban flash floods.

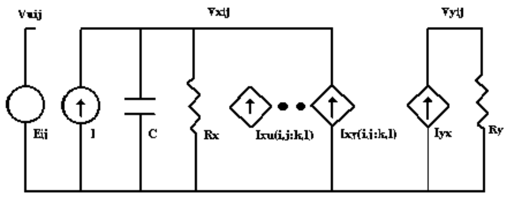
CNN is a natural and flexible framework for describing locally interconnected, simple, dynamic systems that have a lattice-like structure (figure 6). They consist of arrays of essentially simple, nonlinearly coupled dynamic circuits containing linear and non-linear elements able to process in real time large amounts of information.

Fig 6 – Lattice-like structure of a CNN



The main advantage of this novel architecture (Fortuna et al, 2001) is that it is easily suitable for analog implementation (figure 7). Their structure, tailor made for VLSI (Very Large Scale Integration) realization, has led to the production of some chip prototypes that, once embedded in a computational infrastructure, produced the first analog cellular computers. This new architecture is able to perform time-consuming tasks, such as image processing and PDE solution.

Fig 7 – VLSI implementation of a CNN



The equation that regulates the behaviour of a CNN structure, is:

$$\dot{x}_{i,j}(t) = -x_{i,j}(t) + A * y_{ij}(t) + B * u_{ij}(t) + I$$

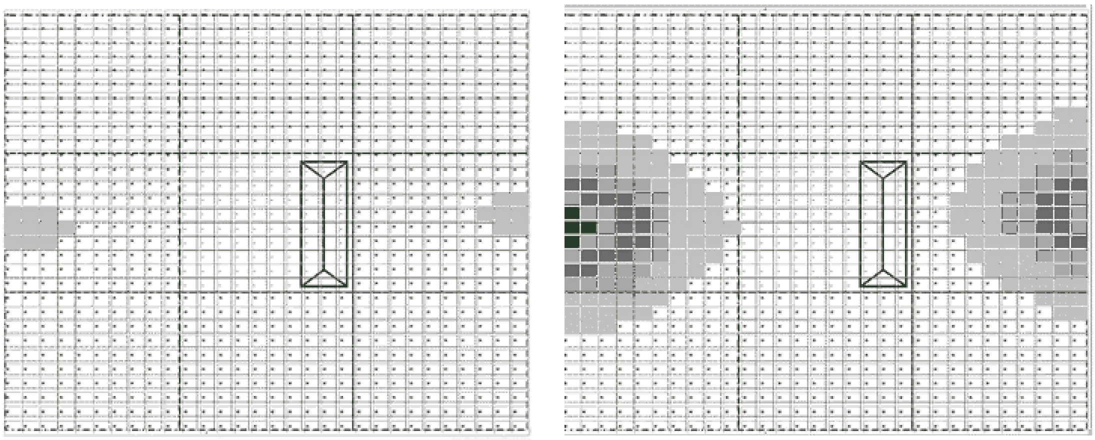
where *u(t)* is the input of the cell, *x(t)* represents the state variable, *y(t)* is the output of the cell, and *A* and *B* are, respectively, the feedback template coefficients and the control template coefficients. The feedback and control template represent the coupling coefficients of the cells and they completely define the behaviour of the network with a given input and initial condition. *I* represents the Bias term used to model the watershed topography.

It is shown (Chua et al., 1995) as a paradigm for several spatio-temporal phenomena occurring in reaction diffusion PDEs. In particular PDEs and CNNs share the property that their dynamic behaviour depends only on their local interactions. Recently CNN has been used as solver of PDE for several complex tasks as lava flow modelling (Del Negro et. al, 2005). Therefore in this project CNNs have been used to solve the Navier-Stokes equation of fluid motion.

Results

Hazardous platform is still under implementation. Two prototypes climatic and hydrometric stations are going to be installed. In particular in the urban area of Catania 6 rain gauges and 5 hydrometric gauges, able to measure the water level in the urban drainage network, are being located. In the urban area of Palermo 2 rain gauges and 2 hydrometric gauges, are being located as well. Hazardous platform will supervise all the climatic and hydrometric stations by using a wireless network (GPRS). Hazardous will integrate these data with the existing climate network owned by the Hydrographic Office of Sicily. The CNN simulator is actually under implementation. The following figure shows some preliminary results of a flood propagation in a test scenario, provided by the CNN simulator.

Fig 8 – Modelling water flood by CNN



Conclusion

In this paper the preliminary results of Hazardous research program, actually in progress, has been described. In particular this paper shows the approach used to integrate the GIS component with the heterogeneous remote sensing system and with the real time model used. A novel supervisory platform has been designed, in which data brokerage services have been extended to ensure semantic interpretation of heterogeneous software services and data, and to ensure their reconciliation in case of semantic conflict. An ontology has been designed, which is able to manage several kind of relations among spatial entities, and spatial process models. A CNN framework has been used to design a real time simulator which is used to simulate in real time urban flash flood.

References

Artale A., Dixon C., Fisher M., Franconi E. (editors) (2004). Special Issue on Temporal Representation and Reasoning (TIME). *Journal of Logic and Computation*, volume 14, number 1, 2004. Oxford University Press. ISSN 0955-792X.

Brown D.G., Riolo R., Robinson D.T., North M. and Rand W. (2004). Spatial Process and Data Models: Toward Integration of Agent-Based Model and GIS, *Journal of Geographical Systems*, University of Michigan.

Cavalieri S., D'Urso F., Floridia C., and Rossettini A., (2004). A Middleware for the management of large utilities Plants. *6th International Conference on Enterprise Information Systems*, Porto, 14-17 April 2004.

Cavalieri S., D'Urso F., Floridia C., and Rossettini A., (2004). Definition of a generalised interface for management of Large Utilities Plants. *2004 IEEE International Symposium on Industrial Electronics*, Ajaccio, 04-07 May 2004.

Chua L. O., Yang L. (1988). Cellular Neural Networks: Theory and Application, *IEEE Transactions on Circuits and Systems*, vol. 35, pp. 1257–1290, 1988.

Chua, L.O., Hasler, M., Moschytz, G.S. & Neirynck J. (1995). Autonomous cellular neural networks: a unified paradigm for pattern formation and active wave propagation, *IEEE, Trans. Circuits Syst-I*, 42 (10) (1995) 559-577.

Del Negro C., Fortuna L., Vicari A. (2005). Modelling lava flows by Cellular Nonlinear Networks (CNN):preliminary results, *Nonlinear Processes in Geophysics*, 12, 505–513, 2005

European Commission (2000). *Workshop on future and emerging control systems*. Available at ftp://ftp.cordis.lu/pub/ist/docs/ka4/report_controlws.pdf.

Fortuna, L.; Arena, P.; Balya, D.; Zarandy, A. (2001). Cellular neural networks: a paradigm for nonlinear spatio-temporal processing. *Circuits and Systems Magazine*, IEEE Volume 1, Issue 4, Fourth Quarter 2001 Page(s):6 – 21

Isermann, R. (1997). Supervision, fault-detection and fault diagnosis methods. An introduction, *Control Eng. Practice*, Vol. 5, No. 5, (1997), pp 639-652

Isermann, R. (2004). Model based fault detection and diagnosis: status and Application ,16th IFAC Symposium on Automatic Control in Aerospace, St. Petersburg Russia,.

Murray R.M., Astrom K.J., Boyd S.P., Brockett R.W., Stein G.(2003).Future directions in control in an information-rich world. *Control Systems Magazine*, IEEE, Vol. 23,No. 2, (2003), pp 20-33

Ploix, P, S. Gentil, and S. Lesecq (2003). Isolation decision for a multi-agent-based diagnostic system. *SAFEPROCESS'2003*, Washington D.C., U.S.A.

Studer, R.M., V. R. Benjamins, and D. Fensel (1998). Knowledge engineering: principles and methods. *Data and Knowledge Engineering*, 25(1-2), 161–197.

Szolgay P., Vörös G., Erõss Gy. (1993). On the Applications of the Cellular Neural Network Paradigm in Mechanical Vibrating System, *IEEE. Trans. Circuits and Systems-I*, Fundamental Theory and Appl., vol. 40, no. 3, pp. 222-227, 1993.

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Author Biography

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I'm employed by Proteo S.p.A as an expert on R&D projects. The type of research is in the field of ICT for environment including the whole water cycle. Proteo is a SME which develops innovative ICT solutions addressed to the optimal management of water, gas, electric and telecommunication utilities.

My specialist expertise is in the field of IT solutions for the environment and risk management; these systems are based on the integration of GIS, SCADA, DSS, to provide environment/water systems monitoring and control, using AI (RBES, CBES), soft computing (GA, fuzzy logic, ANN), and numerical models (CFD).