HAZARDOUS – FLOOD EARLY WARNING SYSTEM

Roberto Gueli

Proteo S.p.A., via Santa Sofia, 65 – 95123 Catania, Italy[1]

Alberto Valenti

Proteo S.p.A., via Santa Sofia, 65 – 95123 Catania, Italy2

Giuseppe Ragonese

IdrAmbiente S.r.l., Viale delle Scienze, Edificio 16 – 90128 Palermo, Italy

Franco Mereu

Civil Protection Office of the Town of Palerm, Via IV aprile, 4 – Palermo, Italy

Maurizio Palermo

Civil Protection Office of the Town of Catania, Viale Felice Fontana, 23 – Catania, Italy

Salvatore Perrone

Fire Department of Campania Region, Via Manzoni 44 , 80123 Napoli, Italy

Keywords

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

Abstract

In this paper the results reached during the Hazardous research program, will be showed. Hazardous is supported by the POR Sicilia 2000-2006 Mis. 3.14. The coordinator of the project is Proteo S.p.A., an Italian SME specialized in developing ICT solutions for environment; program partners are the University of Palermo, the offices of Civil Protection of the cities of Catania and Palermo, the Fire Department of Campania Region, and the Hydrographic Office of Sicily.

The main aim of Hazardous is the design of an urban flash flood early warning system. In particular in this memory it is shown the assessment process used to validate Hazardous' approach. This task has been mainly pursued by the civil protection agencies involved in the project. The test activities has been carried out by using two prototypes of Hazardous system, which have been implemented and located in the two biggest cities of Sicily, Catania and Palermo. In particular a storm tracking strategy has been pursued in order to warn on time the resident population and rescue teams.

The chain of warnings has been tuned and it has been integrated in the chain of command of the protection agencies involved in the project. Main goal of this task is the assessment of the whole early warning process and the sharing of the lesson learnt.

[1] gueli@proteo.it
[2] valenti@proteo.it

Objectives

The activities of Hazardous project are aimed to the implementation of integrated technologies, protocols and territory control strategies for forecasting, preventing and mitigating flash flood risks in urban and peri-urban areas. Flash floods have concentration time that is not compatible with the most part of traditionally accepted Civil Protection actions that are based on human intervention and the definition of operative panels and decision chains that usually are not compatible with the time scale of the phenomena (between some minutes and one hour). The project will integrate prevention and control strategies based on high technology sensors (rain and water level gauges) for collecting and managing data and automatic procedures (traffic lights; automatic traffic diversion; SMS/MMS alert deployment) for reducing the time between the definition of alert condition and the communication to operators and population. The system is based on robust hydrological thresholds based on off-line modelling and able to integrate information, such as weather radar and storm tracking techniques.

Introduction

Flash floods are an important problem in most of the Mediterranean catchments resulting from severe thunderstorm typical of these regions. High intensity short duration rainfall events can cause extreme flash flood conditions resulting in loss of life, property damage and expensive emergency response. It is also well known that debris flows are triggered by short intense storms and constitute a major threat for several urban settlements located on the hillslopes of mountain catchments and for other infrastructures such as highways and motorways. Both flash floods and debris flows are characterized by their small space and time, generally occurring in small catchments, and often beginning even before the cessation of the rainfall that produces them. Given their relatively short lead time, societal responses to these kind of hazards depend only partially on forecasting capability. Even if real time forecasting is a key element to improve the civil protection achievements to mitigate damages and safeguard the security of people, a meaningful societal response might not be performed without the development of considerable infrastructure to allow a society to respond properly and in time to mitigate these kind of hazards (Doswell, 2005). In particular the emphasis is increasingly put on communication infrastructures for potentially affected people information and involvement in disaster prevention and preparedness (Wagner, 2007). Since small basins are widely distributed, they affect different kind of urban infrastructures, owned by different public and private bodies and involving different kind of communities, as for example residential people, commuters or tourists. In particular, the latter communities have led to the growing frequenting ever increasingly geomorphological fragility, visitors who live only for a short time in the area and who are often inadequately prepared in terms of skills, experiences and equipment (Brandolini et al., 2006). Urban flooding is also expected to impact more often in Europe and in particular in the Mediterranean area, and main pressure factors are:

- Climate changes
- growing urbanization
- ageing of drainage infrastructure

The consequence is that people should accept that flooding in the urban area is normal. This means that runoff should be managed on the surface (roads), and during a heavy rain the excess water would be directed from roofs, roads and paving to low value areas, safeguarding houses and critical infrastructures. But in this case frequent short term flooding has of course a relevant impact on the economic and social structure of urban life, and it isn't well investigated the degree of bearableness (in both economic and social terms) of this kind of events. In the following pictures two different flood effects are shown. The first one (fig 1) could be classified as an irritating situation, with an impact on urban mobility (the footbridge is a sign of flood habit). The second one could be instead classified as a danger situation in which both the water speed and its depth might be risky for life. In particular water speed is a risk factor too often neglected, because of expensiveness of flow gauging in an urban environment.

Fig. 1: flood impact on urban mobility

Fig. 2 impact of shallow flow velocity

If urban flooding is generally accepted to impact more frequently than previously assumed, several new questions should be approached and solved, in order to make possible to cohabit with this kind of hazard. In particular online data gathering, harmonization and effectively delivery to potentially affected people is a key issue, in order to engage population to behave in a responsible way and to take care of themselves, providing a knowledge based information system in order to engage population to behave in a responsible way and to take care of themselves inasmuch possible, reducing in such a way working load of emergency forces and health care units, while limiting panic and disorganization (Paton and Johnston, 2001). Many of deaths and injuries associated with flash and debris flows are transportation infrastructures related. Roads are the basic part of the urban texture supporting social and economic activities. From this point of view, road system is the most critical infrastructure for both territorial integrity and disaster management. In addition, this infrastructure, which is more in general only a component of a more complex multimodal transportation system, is strongly linked with other kind of technological networks as for examples: water supply, urban drainage, gas supply, telecommunication infrastructure, and electrical power system. In the following figures show the impact of a heavy convection rain, that occurred on the east cost of Sicily on October 14th, 2006. It was a Saturday afternoon, in less then 30' an average rain of 80 mm fell down on the city of Catania.

Fig. 3: 02:30 PM Sicilian east cost highway

Fig. 4: 02:50 PM Sicilian east cost highway

Three years before, the October 15th 2003, at 01:30 PM of a working day, an other severe thunderstorm occurred on the Ionic cost of Sicily. Even if the rain fallen down was less then during the event of 2006, the consequences were decidedly more dramatic, because of the number of people affected by the flood while going home, for the lunch time period. In particular a young woman drowned in a street of the city, while trying to face the runoff shallow flow, with her moped.

The research on the loss of life in this kind of tragic events suggests to improve the quality of such an analysis by using hydraulic modelling, instead more commonly used hydrological approach, in order to correctly estimate the runoff flow velocity from roads.

Hazardous architecture

The main goal of Hazardous platform is urban flash flood nowcasting and warning. 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 (Gueli, 2007).

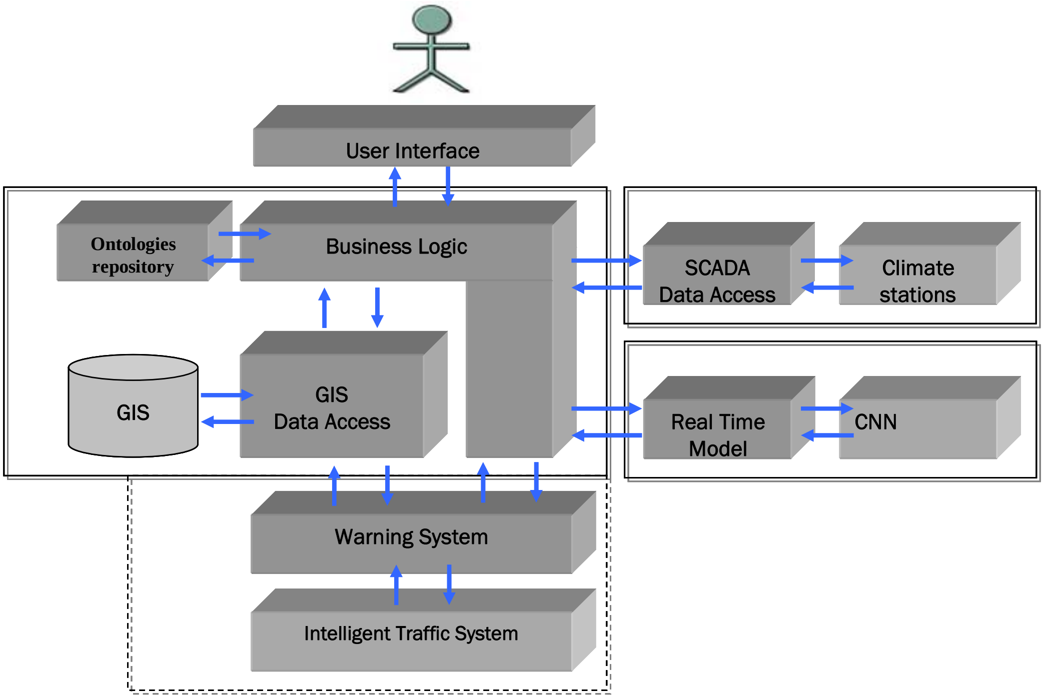

Fig. 5:Hazardous architecure

Afterwards 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 warning the people in danger, is a network of 15 electronic signs suitably distributed in the urban area (fig.6).

Fig. 6: electronic flood warning signs

Hazardous platform masters and integrates a 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 by this way to nowcast flash floods, and then to provide early warning about the imminent hazard.

Since the existent climatic sensor networks don't cover the city centre, six additional rain gauges have been installed following two parallel paths (fig 7) in order to try to track the storms.

Fig. 7: rain gauges placement

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.

More in general 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 kind 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 viceversa.
- *Events*: set of events which can happen; each event impacts on one or more elements, and an element can trigger events.

The monitoring network has been implemented by using the Nokia N12 modem, which is equipped with J2ME virtual Java Machine. The six devices are connected with the Hazardous' SCADA system by using a GPRS wireless connection to an internet host. GSM GPRS/EDGE cellular data networks use a mechanism called an APN (Access Point Name) to determine how a wireless connected device communicates via the GSM network to a host site (i.e., how the carrier network passes IP traffic to the host network). An APN determines what IP addresses are assigned to the mobile station, what security methods are used, and how the GSM data network connects to the customer's network. In particular Hazardous uses a public APN, in which the IP is dynamically assigned to the wireless connected device at each connection.

Off line modelling

In order to figure out urban flood triggering factors, some kind of hydrological precursors can be considered to improve the effectiveness of the emergency actions (i.e. early flood warning). In fact, in these small urbanized catchments, in which flooding occurs rapidly, the forecast lead time may not be long enough to allow the use of rainfall-runoff models that transform past observed rainfall into runoff. So in this case the use of flood precursors implemented off-line and compared in real time with observed or predicted rainfall depths results in a practical alternative. Rainfall thresholds are a fundamental element of the implementation of the real-time warning system that we propose to develop.

In order to define the urban flood precursors a rainfall-runoff dual model based on the double order approximation (DORA) methodology has been used (Nasello and Tucciarelli, 2005). In urban areas, when heavy rains occur, the discharge capacity of sewers is usually unable to transport the effective rainfall reaching the streets (fig. 8). When the runoff flow rate exceeds the capacity of the storm sewer system, the excess flow is conveyed through the street network as overland flow. D.O.R.A. methodology is proposed for modelling the system as a double network, formed by an upper network of open channels (street gutters) and a lower network of closed conduits (sewer pipes). What is new in this model is its capacity to take into account the hydrodynamic relationship between the flows in the upper and lower networks.

Fig. 8:D.O.R.A methodology

Real time modelling using CNN and ANN

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 flood.

CNN are a natural and flexible framework for describing locally interconnected, simple, dynamic systems that have a lattice-like structure (figure 9). 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.

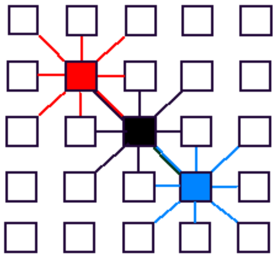

Fig. 9: Lattice-like structure of a CNN

The main advantage of this novel architecture (Fortuna et al, 2001) is that it is easily suitable for analogic implementation. 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 analogic cellular computers. This new architecture is able to perform time-consuming tasks, such as image processing and PDE solution.

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) are 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 has been used to solve the Navier-Stokes equation of fluid motion.

Results

Hazardous platform already implemented. Two prototypes climatic and hydrometric stations have been installed. In particular in the urban area of Catania 6 rain gauges have been located. In the urban area of Palermo 2 rain gauges and 2 hydrometric gauges, have been located as well. Hazardous platform supervises 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.

Furthermore a novel adaptive artificial neural network has been implemented in order to automatically detect the most sensitive rain value precursors. The implemented algorithm detects the most sensitive rain value precursor readapting consequently the neural network architecture. It should be noted that this novel algorithm ever found different neural network architectures in order to perform runoff forecasting, when rainfall is at its beginning or nowcasting, when rainfall is at its peak. This fact means that an early warning platform should be able to integrate a complex set of real time models instead a simple one. In the following figures has been shown the forecast and the nowcast capability of the implemented set of neural networks.

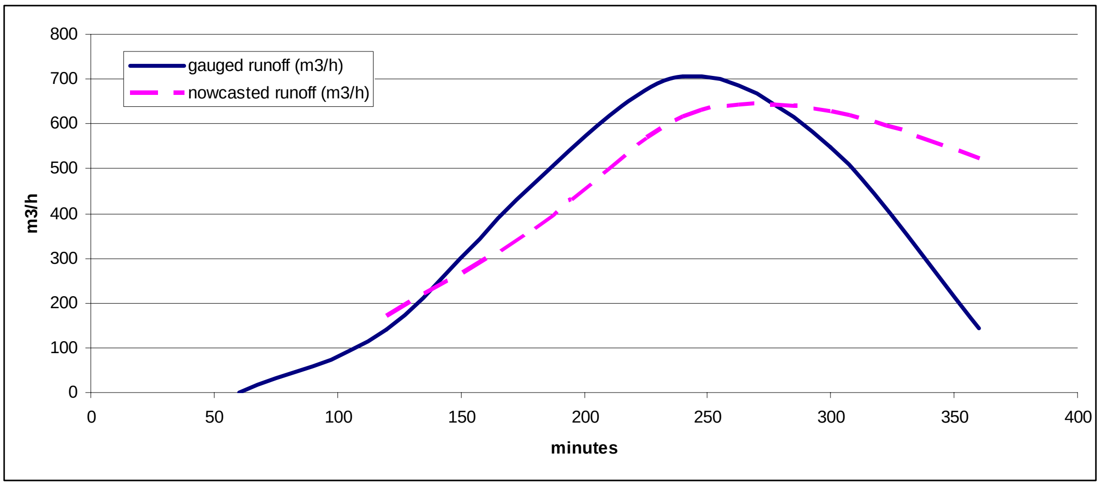

Fig. 10: runoff nowcast

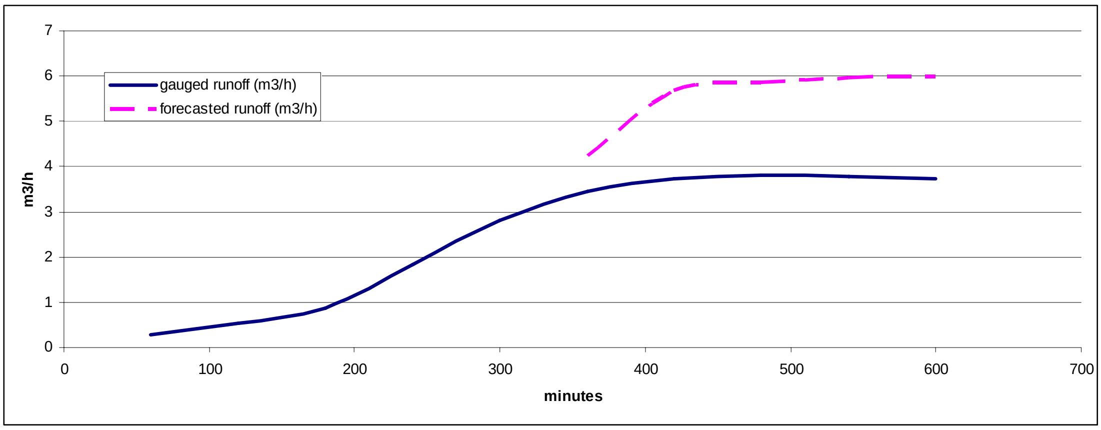

Fig. 11: runoff forecast

It should be noted as the implemented neural network overestimates the forecasted runoff.

Conclusion

In this paper the Hazardous architecture 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 are used to simulate in real time urban flash flood.

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Acknowledgements

The Hazardous research project is supported by the POR Sicilia 2000-2006 Mis. 3.14.