Sensornet Early-warning System Integration

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Abstract: In order to increase the resilience of the regional territory to extreme rainfall phenomena, LepidaSpA has enhanced an already existing IOT platform, Sensornet, created to manage heterogeneous sensor networks extended all over the entire territory of the Emilia-Romagna Region, introducing some new data not related to physical measures, such as rivers level or amount of rainfall, but to their forecast. The novelty and the strategic importance of the project presented in this paper is the incremental integration within Sensornet platform of virtual sensors, based on hydrological simulation models and meteorological modelling, sharing the same data model initially defined for physical ones, thus making available not only the continuous monitoring of phenomena and their evolution, but also the generation of early warning in case of critical thresholds with a forecast up to 12/24 hours. The capability to detect forerunners constitutes a fundamental requirement to increase the ability to recognize in advance critical scenarios and to support their management.

1 INTRODUCTION

Sensornet is the Internet of Things Platform of the Emilia-Romagna Region, collecting data and information from thousands of objects distributed across the territory, and building in time a digital map of the reality we live in Figure 1.

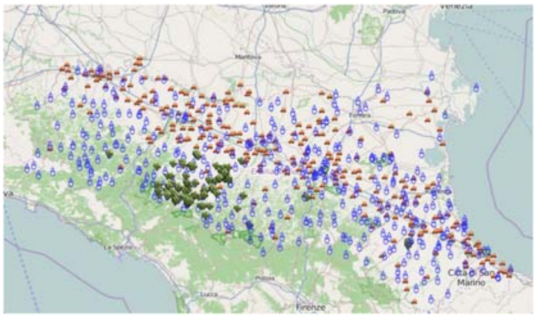

Figure 1: Sensornet platform.

Whether they are generated by inclinometers for landslide monitoring, hydrometric sensors for the level river control, or inductive coils for the traffic monitoring, data generated by the sensors define a snapshot of a reality made of continuously updating information, allowing a better knowledge of what is happening in cities and in territories (Nanni and Mazzini, 2015).

The platform collects measures taken in real time from different sensors and handles automatic reporting when critical conditions are detected such as exceeding thresholds or rapidly evolving phenomena (Figure 2).

The first part of this paper illustrates the needs and objectives from which a new project, related to the support management of extreme rainfall phenomena, has been conceived, with a short digression on the difference between hydrological models to be used in the case of medium and large rivers and in the case of the small ones.

Next section will describe how, after the flooding event of 2014 involving the city of Parma of Emilia-Romagna region, ArpaE (the Regional Agency for Prevention, Environment and Energy of Emilia-Romagna) has developed a hydrological simulation model that allows to know in advance, with a given degree of probability, the approach of critical thresholds of the hydrometric level at some points of observation of the main rivers of Emilia-Romagna region.

The second part of the document outlines the results obtained by the integration of forecast data

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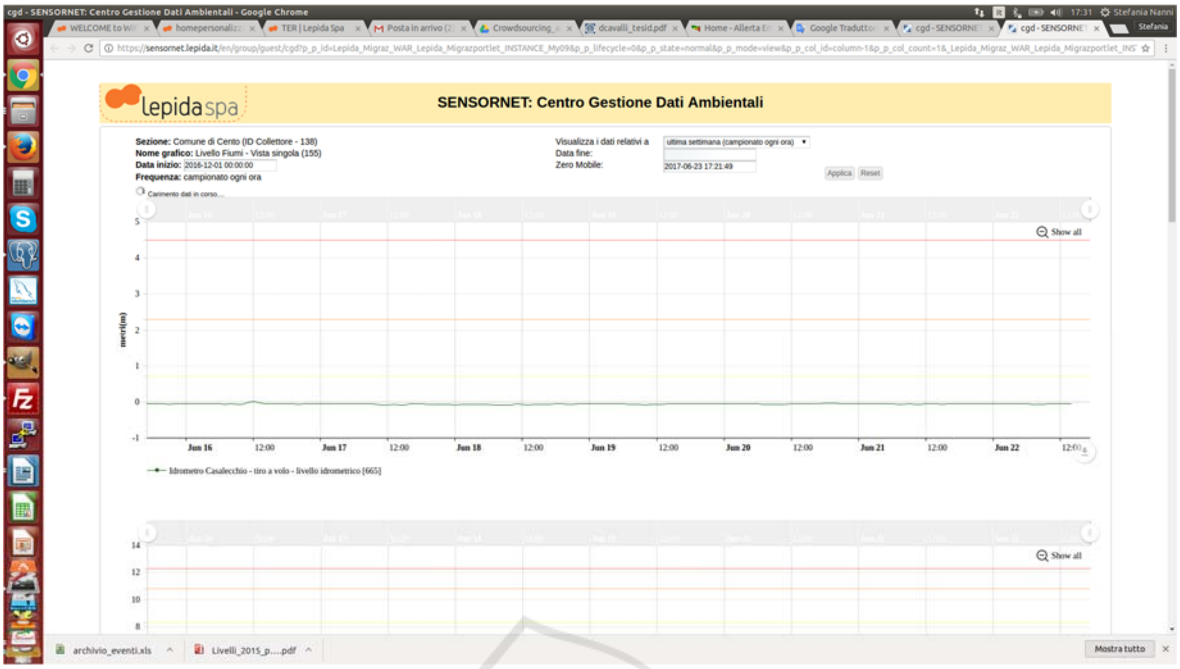

Figure 2: Hydrometric level and relative thresholds.

with the observed ones, related to the management of extreme rainfall phenomena, within the Sensornet platform.

The final part describes the future expected developments.

2 THE STATE OF THE ART

Climate change is affecting all regions in Europe causing a wide impact on society and environment. Recently, extreme weather events as heat waves, floods and droughts have caused rising damage costs across Europe. In future, further impacts are expected to rise societal vulnerability, potentially causing high damage costs, as published by the European Environment Agency (http://www.eea.europa.eu/media/publications/climate-impacts-and-vulnerability-2012).

Recent studies focused on climate change projections over Northern Italy and Emilia-Romagna region reveal that a peak of changes on minimum and maximum temperature is expected during the summer season at the end of the century (2071-2099), when the increase in the average could reach 3.5- 4°C with respect to present climate 1961-1990. On the other hand, significant changes on precipitations are expected during summer, also at the end of century, when a reduction up to 40% is foreseen.

The most obvious effects of these climate changes are the increase in the number of extreme rain events and consequent flooding events, which can have critical consequences especially in urban areas where the concentration of the population and services is higher (Figure 3).

Figure 3: Parma flash-flood October 2014.

Many studies are currently addressing the problem of predicting critical environmental phenomena, including flooding.

Some of them are not based on forecasting system, but rather on real-time monitoring systems (Baxter and Francis, 2000). or on certain percutaneous parameters of the phenomena (Chaczko and Ahmad, 2005, July).

In other cases, the forecasting system is based on the integration of the predictive algorithm in physical sensor networks, and is strictly bound to all the problems and limitations associated with this type of solution (Basha et al., 2008). In other cases, the predictability aspect of the phenomenon is only mentioned as one among many others involving in the management of critical events (Basha and Rus, 2007, December).

The preparation and reaction to such disruptive phenomena can increase the resilience of the territory in short time as early warning of hazardous conditions and in medium term as territorial planning and preparation to emergency response.

The management of extreme rain events can not, therefore, solely rely on traditional real time monitoring systems, but must also include new forecasting systems based on hydrological simulation models and meteorological modeling.

3 RainBO LIFE

The analysis of climate variability over the municipality of Bologna, as resulted from the BlueAp LIFE project (Bologna Local Urban Environment Adaptation Plan for a Resilient City 2012-2015), reveals important changes observed in the main climatological variables.

During the last two decades, years with intense precipitation have been frequently registered in Bologna, having an important impact on the city and its citizens.

The quantity of precipitation shows a slightly negative trend during winter, spring, and summer and a positive trend during autumn, over the period 1951-2011.

With regards to seasonal extreme of precipitations, the dry days index presents a positive tendency over 1951-2011 period, more intense during summer.

Analysis performed on intense precipitation time series evidence a slightly positive trend of the frequency of days with intense precipitation (based on 90th percentile as a threshold) in all season, except on spring.

The flooding risk of small water courses is a major problem in several urban areas (especially in Italy): the constant growth of urbanization, with the consequent decrease of soil permeability and loss of space for river and stream beds, is leading to increased flood hazard and vulnerability; in such conditions, severe rainfall events over steep catchments of limited area can produce dramatic consequences; in addition, ongoing climate changes are likely to increase the occurrence of severe precipitation events, thus increasing flash flood hazard.

Historical and recent records report that the urban areas of Bologna located beneath the highland are prone to severe flood events caused by small water courses.

The most severe event occurred in 1932, when rainfall of 134 mm within a few hours caused flooding of a large urban area, including a portion of the Ravone catchment area.

Another severe flood event occurred in the Bologna area in 1955, while in 2002 a further flood event affected several small municipalities nearby.

In all of these cases, the recorded hourly peak intensity exceeded 50 mm/h.

Despite its relevance, the risk of flooding of small water courses in urban areas is often underestimated and few measures are taken for prevention and mitigation (Grazzini et al., 2013).

The high level objective of RainBO LIFE project (2016-2019), that is a follow-up of BlueApp one, is the improvement of knowledge, methods and tools for the characterisation and forecast of heavy rains potential impact due to the hydrological response, not only of medium and large basin, but also of the small ones and for the evaluation of the vulnerability of assets in the urban areas.

4 HYDROLOGICAL MODELS

4.1 Medium and Large Basins: Random Forest Method

Following the flooding of the Baganza river in Parma on October 2014 (Figure 3), caused by heavy rains, which flooded several neighborhoods southwest of the city, the Civil Protection Agency of the Emilia-Romagna region required ArpaE the development of a hydrological simulation model to be able to recognize in advance the probability of overcoming the three alert thresholds fixed for the main rivers of Emilia-Romagna region: Warning (threshold 1), Pre-alarm (threshold 2), Alarm (threshold 3).

Hydrological modeling for medium and large basins is based on a statistical method, Random Forest, which uses decision trees.

The Random Forest model, applied to hydraulic modeling, provides the probability of overcoming the alert thresholds of some observation point of the medium and large basins, for the next 6-8 hours, depending on the dynamics of the river.

In particular, the Random Forest hydrological model gives the following forecast data:

1. Probability of not exceeding threshold 1
2. Probability of exceeding threshold 1
3. Probability of exceeding threshold 2
4. Probability of exceeding threshold 3

4.2 Small Basins: Criteria 3D Model

Forecasting models of heavy rainfall initiating flash flood from small basins are different from other models (e.g from large basins or waterways).

The size of the small basin results in very rapid response times to heavy rainfall.

In other words, the time interval between the start time of the precipitation and the span peak can be reached in less than two hours, which in reality would make the prediction of the event very difficult and therefore the alert system.

For this reason, it is considered essential to develop a hydraulic simulation model for small basins, and the installation of specific measuring points, allowing hydrometric observations to its validation.

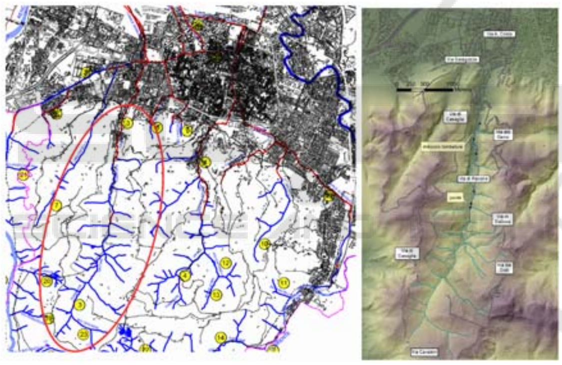

Figure 4: Ravone creek.

Criteria3D is a three-dimensional hydrological model, which also simulates water infiltration into the soil, developed by ArpaE-SIMC of Emilia-Romagna region.

The model was developed starting from the study of the river Ravone, which is one of the creek that from the hills south of Bologna goes down to the city (Figure 4).

In this basin, all those critical and valuable factors that are present in the hilly waters, such as the effects of the strong anthropization that currently characterizes the end of the valley and the crossing of the city, are also present. (Figure 5)

Figure 5: Ravone's suture and measure point.

Figure 6 shows the good result of the test of simulation of the water level at the stream gauge of Ravone in the event of 2015-02-05.

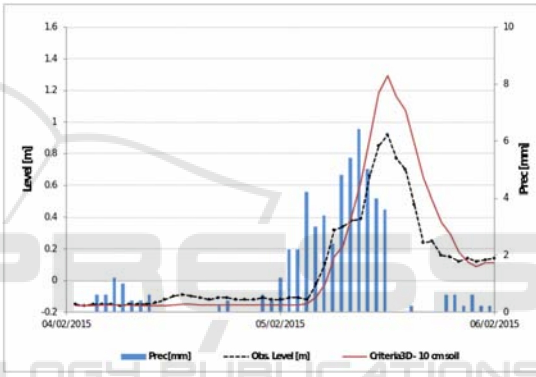

Figure 6: Criteria3D simulation of the water level at the stream gauge of Ravone in the event of 2015-02-05.

5 METEOROLOGICAL MODELING COSMO-LAMI

The numerical meteorological model limited area Cosmo-Lami (https://www.arpae.it/dettaglio_generale.asp?id=2584&idlivello=32), called Lami for brevity, carried out in consortium between national civil protection department, USAM Air Force, Harp ArpaE Piemonte and ArpaE Emilia-Romagna, provides numerical forecasts with a spatial resolution at 7km and 2.8Km and temporal validity respectively three and two days.

Predictions based on this model are carried out twice a day, at 00 and at 12 UTC, at the supercomputing Cineca center, in accordance to a contract with the IdroMeteoClima Service and the Department of National Civil Protection.

Data are provided in grid format, GRIB (http://apps.ecmwf.int/codes/grib/format/grib1/overv iew), and each file contains forecast data for various meteorological parameters, including precipitation, either at the surface or close to it, at an hourly or three-hourly in dependence on the parameter.

The data relating to the meteorological modeling can be used both at the level of maps to have, for example, an overview of the precipitation forecast, but also at the numerical level to have, for example, the detail on hourly precipitation provided on a given grid cell, as in the case of Ravone creek, which constitutes the basic information for the prediction of the hydrometric level corresponding starting from the product simulations scenarios resulted from the 3D hydrological model for small basins.

Data from meteorological modelling, limited to the Emilia-Romagna region, are distributed GRIB format on the open date platform of ArpaE of Emilia-Romagna.

6 SENSORNET EARLY-WARNING SYSTEM INTEGRATION

Sensornet early-warning system integration is based on the integration of forecast data into the platform through the configuration of new virtual sensors based on hydrological simulation models and meteorological modelling.

The integration of these new virtual sensors into the Sensornet platform has been accomplished in a simple and immediate way, using the same data model defined for the physical sensors, without the need for any extension or specialization and providing the platform with a new feature crucial for recognition and generation of early-warning reports.

6.1 Sensornet Forecast Data Integration

Sensornet constitutes the monitoring subsystem of RainBO platform.

In addition to the data coming from the traditional real-time monitoring system of ArpaE, mainly consisting of regional hydrometers stations to measure temperature, rain and hydrometric levels, it also integrates those belonging to the forecast systems, for the scope illustrated before.

The integration of sensors data coming from different monitoring systems in Sensornet is realized through a federated approach whose main advantage is to preserve the investments made on already existing systems and to protect the technical, technological and organizational autonomy of the individual systems and of their owners.

The architecture implemented in Sensornet platform provides an interconnection middleware between the different data sources and the central system, acting as a data collector from different sources and a data normalizer towards the central system, as shown in Figure7.

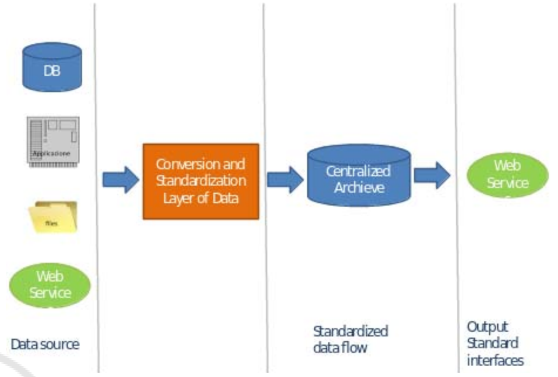

Figure 7: Flow of collection, standardization, storage and access of the data.

It consists of a series of atomic modules for data retrieval from individual sources and of their manager, which oversees their activation and coordination.

Each module contains the access rules and the required commands for retrieving data from a specific source or database and for storing them in a standard format on the centralized database.

In order to acquire data from heterogeneous sources and use them in a contextual and correlated mode, a standardization process is necessary.

The creation of a standardized data stream is one of the added values offered by Sensornet platform, which transforms the data from the different sources into a single standard format, regardless of the technologies, the interfaces, formats and data type of the sources (Nanni and Mazzini, 2015).

The integration of the hydrological simulation models and meteorological modelling data in Sensornet has been achieved through the definition of "virtual" sensors, which, unlike the real, are not associated with physically measured data, but to the forecasted ones provided by the models.

This type of solution allowed to completely integrate these new types of "virtual" sensors with the real ones, while maintaining the consistency of data and their modeling within the Sensornet platform.

6.1.1 Lami Virtual Sensor Integration

The new "virtual" Lami sensor has been defined in Sensornet platform to allow the integration of the GRIB data related to the modeling of the weather, needed for the 3D hydrological simulation model for small streams.

In the case of the Ravone stream, as in most small streams, the size of the basin is contained in a single cell of the reference grid, whose data can then be represented by a sensor placed within the cell itself.

From the datum for cumulative rain, collected from GRIB data at the beginning of each run for each cell, it is possible to calculate the corresponding precipitation per hour.

Once a precipitation threshold has been established, it is possible to determine when a precipitation starts and when it finishes, to infer the duration as well as the peak and the accumulated of the corresponding event.

The algorithm to calculate the significant parameters of a rainy event, starting from the data for the cumulative hourly precipitation, can be described as follows:

- starting from the GRIB data (the cumulative hourly precipitation from the beginning of the run), the hourly precipitation is extracted with simple subtractions;
- the hours in which rain is expected and when it is not (0-1) are calculated according to the established threshold (normally 0,2 mm);
- depending on the distribution of 0 and 1, it is estimated when a rainy event starts and when it ends;
- at this point it is possible to calculate the duration, the accumulated (constitutes from all the hourly precipitation included in the event) and the maximum intensity relative to the event (peak).

The storage of the main parameters of a rainfall event, calculated as it has been described, is made by defining four corresponding measures associated with each "virtual" Lami sensor:

- hourly precipitations
- event
- cumulative hourly precipitations
- peak

The integration of the new type of Lami virtual sensor inside the Sensornet platform, indeed, required the implementation of a new GRIB data acquisition and processing module, the definition of a new type of Lami sensor, to which the four measures previously described are associated, and the configuration of a new Lami type sensor at the Ravone stream, identified by the coordinates of the corresponding grid cell.

The integration of other sensors related to the meteorological forecasts at another stream, simply requires the configuration of another Lami type virtual sensor associated with the coordinates of the corresponding grid cell.

Figure 8 shows an example of graphing data for the Lami sensor defined for the Ravone cell (lat 44.46 and lon 11.31) provided at 00:00 on 30/06/2017 and valid for 72 hours later.

In the example shown, the expected rainfall is below the defined threshold (normally 0,2 mm) and is therefore not a source of rain for a rainfall event.

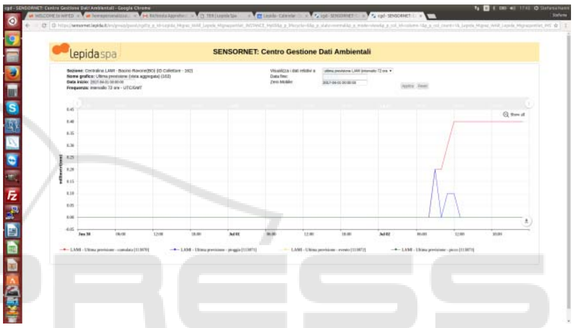

Figure 8: Example of graphic data of Lami virtual sensor.

6.1.2 Random Forest Virtual Sensor Integration

The new "virtual" Random Forest sensor has been defined to allow the integration the data related to hydrological modeling for medium and large basins.

The integration of the new type of Random Forest virtual sensor inside the Sensornet platform required the implementation of a new data acquisition and processing module of the .csv files (provided by ArpaE every 10 minutes on a ftpServer, hosted by LepidaSpa), the definition of a new type of Random Forest sensor, to which the previously described four probabilities are associated, and the configuration of two new Random Forest type sensors in correspondence of Parma and Baganza rivers, identified by the station ID of the corresponding hydrometer.

The integration of other data related to hydrological modeling for medium and large basins, simply requires the configuration of others Random Forest type virtual sensor associated to corresponding .csv files.

Figure 9 shows a graphical representation data for the Random Forest sensor defined for the Baganza river provided at 14:40 of 18/07/2017 and valid for 6 hours later.

In the example, the probability of the river level of not exceeding threshold 1 in the point of observation is equal to one, while the probability of exceeding threshold 1, threshold 2, and threshold 3 is equal to zero.

Figure 9: Example of virtual sensor Random Forest data graphication.

7 SENSORNET EARLY-WARNING SYSTEM INTEGRATION RESULTS

The term early warning (EW) indicates alarms that arise in the time interval between the moment in which phenomena potentially triggering a dangerous event are observed and the time at which the event happens.

Time scales characteristic of early warning are different for different types of events:

- from seconds to tens of seconds for earthquakes;
- from minutes to hours for tsunamis;
- from hours to days for weather events;
- from hours to days to floods and landslides;
- from hours to weeks to volcanic eruptions.

The adoption of early warning (EW) methodologies is considered as essential to cope with disasters (not just natural) in a world where the population is not only increasing, but it is concentrated in megacities of several (or even tens) millions of inhabitants.

In fact, the EW appears as a keyword in all documents addressing the problem of risk reduction, both nationally and internationally (Baxter and Francis, 2000).

With regards to hydraulic risk, the possibility of early detection of extreme precipitation events and their effects on the river level allows to recognize in advance critical scenarios and to support their management or, vice versa, to give evidence of the absence of critical conditions.

Figure 8, for example, shows the rain forecast for the next 72 hours on Ravone's cell.

The graph gives evidence of the expected rainfall and its cumulated level, whose duration and intensity are not sufficient to generate a significant event to report.

Figure 9 shows that the probabilities of the level of Baganza River to not exceeding threshold 1 is one, while it is equal to zero the probability that it exceeds any of the three defined alert thresholds, for the next 6 hours.

Integration of forecast model data is the right prerequisite for the creation of an early-warning system that allows recognition and signaling of critical thresholds over with an anticipation that depends on the simulation model used.

In particular, the integration of forecast data related to the hydrometric level for medium-sized basins and rainfall events for small ones allows to identify critical scenarios in advance with a margin of some hours in the case of medium-sized basins and up to a few days for those little ones.

According to the previous time scales the forecast data integrated in Sensornet platform provides the right conditions for the provision of an early-warning system effective and useful for the management of extreme rain events and floods events.

8 CONCLUSIONS

RainBO LIFE is a very ambitious project that aims to provide a support platform for the management of extreme precipitation events both in the medium term as territorial planning and preparation to emergency response and in short time as early warning of hazardous conditions.

Sensornet platform, that constitues RainBO monitoring subsystem, was already integrating the data of the major traditional monitoring systems, but its modular, flexible and configurable architecture allowed immediate integration of the forecasts ones, from which it depends the increase of resilience of urban areas through the early warning of hazardous conditions.

The support for the management of extreme precipitation events in the short term also includes the integration of innovative technology-based monitoring systems, such as microwaves links, which can provide rainfall measurement from the attenuation level of radio signals of the base radio stations of the cellular networks.

Once the radio data acquisition module will be finalized, Sensornet will also integrate new virtual sensors corresponding to the intermediate point of the radio links, for which the signal attenuation data stream will be available.

This new type of virtual sensors will be another added value of Sensornet platform, and therefore of the monitoring subsystem of the RainBO project.

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