An Integrated Infrastructure for Distributed Waste Water Quality Monitoring and Decision Support

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***Abstract*— : Waste water management plant protection is a major concern for water cycle management entities. The rapid identification and possible localization of anomalous or even malicious waste liquids immissions may allow for undertaking pollution risk mitigation actions (e.g. using of ancillary basins) and reduce maintainance costs. Pervasive monitoring of the transport network is hence needed although economic and technical issues prevent its implementation. The SIMONA project is aimed to design, deploy and test an integrated, intelligent, pervasive monitoring infrastructure based on a network of low cost/low mainteinance quali-quantitative multisensor nodes. A scalable data processing facility permit the ingestion and the processing of the data stream while a set of models provide for quali-quantitative forecasting increasing the manager situational awareness about the smart infrastructure. All the information is made available via a GIS based Web HCI.**

Keywords—sensor networks;waste water management; decision support

I. INTRODUCTION (*HEADING 1*)

The modern smart city concept significantly involves the optimal management of the several utilities at the base of the city life. In the last few years, there is a growing concern about environmental issues due to the unlawful or uncorrect urban and industrial drains into the sewer. These in turn may induce catastrophic effects on the waste water management plants and significant damages to the environment and economy of the affected city (see Fig.1). The capability to distributely monitor the sewage transport process and prevent damages to the waste management plant as well as pollution events is hence nowadays highly relevant and actively researched [1]. SiMONA (Integrated System for Environmental Monitoring) is a research project that aims to build an innovative infrastructure for decision support in waste water networks management based on pervasive monitoring. The monitoring process is carried out by a hybrid network built up by inexpensive smart sensors and commercial available multisensory devices.

The main goals of SIMONA process are actually the remote monitoring of water quality along the sewage infrastructure, the identification of anomalous/malicious drains along the infrastructure and the production of water quality forecasting in several significant nodes including waste water management plant. In order to reach these goals, several challenges should be tackled including the limited knowledge on sewage network infrastructure that generally affects the infrastructure management entities. Moreover, the applicative framework generates additional constraints like the strongly heterogeneous connectivity availability along the network, the high cost of sensor mainteinance/recalibration that is needed for contact sensors due to harsh conditions and sewage water aggressiveness, the complexities of source localization problem and the non stationary behavior of the sensed variables that preclude the use of simple anomaly detection algorithms. These constraints have been tackled with ad-hoc design and development actions.In this work, we intend to present the SiMONA infrastructure, introducing the global architecture and its base components.

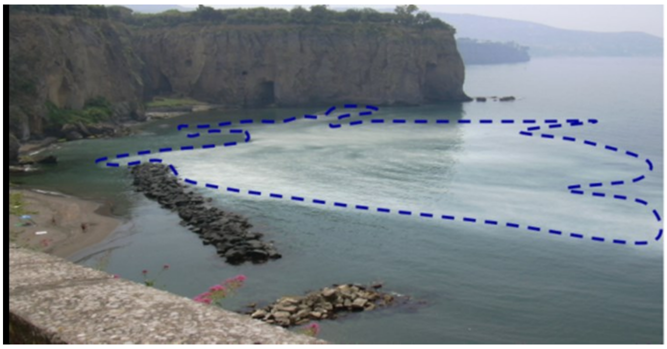

Fig. 1:Effects on the sea water of waste water management infrastructure malfunctions.

II. SIMONA ARCHITECTURE

A. *Architectural Design*

The SIMONA project infrastructure is built up my multiple components organized in different levels. In Fig. 2 these layers are outlined. From left to right the semantic content of the information is augmented starting from the raw signal readings to high level human to computer interface fed by computational intelligence based data processing components.

In the following we briefly outline the layers motivations and adopted solutions.

Monitoring sensor network componets represent the first layer of Simona architecture. Waste water networks represent a very harsh environment for sensory systems. By requirement, the use of contact sensors, partially obstructing the water flow, should be avoided. Waste material can in fact become trapped by the sensory system and totally obstruct the pipe. Furthermore the aggressive fluids are capable to induce heavy drifts in the transducers; for this reason, every contact sensor should be repeatedly calibrated and so they must be installed in frequently visited and easily accessible places. The SiMONA sensory network is in fact based on 4 class of sensing devices, each one having his own target and mission. The first sensing class is characterized by small low cost sensors aiming to monitor the presence of water in bypass links, in which water is foreseen to flow only in specific conditions (e.g. heavy rainfall events). The second class is characterized by intelligent low cost multisensing devices aiming to detect anomalous conditions by monitoring a set of meaningful parameters such as H_2S concentrations, noise, water temperature (remotely), level with non-contact sensors. An on-board intelligent sw component, based on artificial immune system paradigm, is devised to detect and signal anomalies. The third class of sensing devices is characterized by commercially available multisensing devices monitoring pH, Conductivity, NH_3 concentrations, Suspended Solids, COD and Temperature with contact sensors. The fourth class of sensing device is instead characterized by an optical sensing device that, based on IR and UV reflectance, aim to quantify Suspended Solids and COD called Loadmon. Low cost multisensing device rely on GSM networks, for maximum coverage, to signal significant events by sending SMS while commercial multisensing device rely on standard links normally used for remote control by SCADA systems of the network management institution. The deployed sensory network is aimed to feed a single point of access system (datasink) from which incoming data are stored in a NOSQL database based on MONGODB management system. Networking facilities and storage sytems represent the second and third layer of the architecture, respectively. An orchestrator sw system is designed to retrieve data from the NOSQL repository in order to feed a set of network models capable to analize data so to provide water quality forecast along the network, detection and qualification of anomalies, and localization of anomaly water immissions. The core of the forecasting model is built around SWMM5 ([2]) simulator that is customized for the particular waste water network and by means of sensor readings provide forecasting of water quantitative and qualitative parameters in several nodes along the network including tha most important one being the inlet of the waste management plant. Forecasting are provided at +2hrs, +4hrs, +6hrs and +8hrs. A rule based network anomaly conditions detection is based on a set of business specific rules powered by the Drools BRMS. These components represent the basis of the fourth architectural layer. The source localization algorithm is instead based on a genetic algorithm approach powered by the use of GALib and SWMM5 forward simulations. Practically a population of possible sources are evolved by seeking the minimization of the difference from forecasts and observations in the measured nodes. The approach and generally, the problem formulation does not guarantee a unique solution, but a set of possible location are produced as output to be further screened by human operators. Both the forecasting model and Drools output are modelled as virtual sensors providing numeric or class based output to be visualized by the HCI system (fifth layer). Finally, the GIS powered HCI system is based on the OpenGIS [3] specification and specifically on the 52North platform.

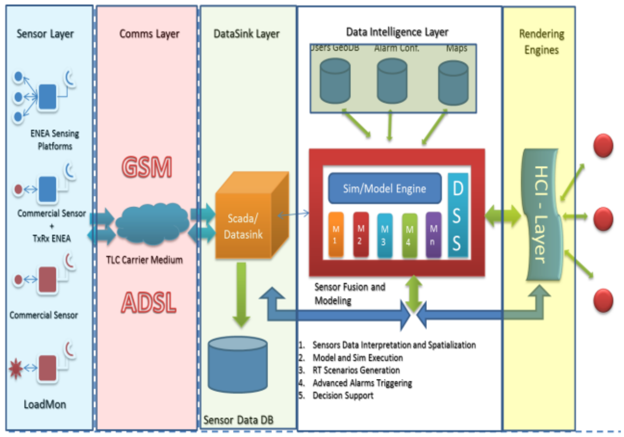

Fig. 2:The Simona software architecture design.

III. BACKEND TECHNOLOGIES

Data inception layer rely on several componets (see Fig. 3). Inception is performed by multiple adapters implemented on RaspberryPi systems acting as network datasinks. Their goal is to receive SMS alarms from low cost sensing devices, actively query the Loadmon device and receive data streams from conventional commercial analyzers. Captured data is then stored on a highly scalable MongoDB based storage system. A NodeJs based orchestrator provide the information exchange infrastructure and activate water quality and quantity forecasting models feeding them with real time sensors data.

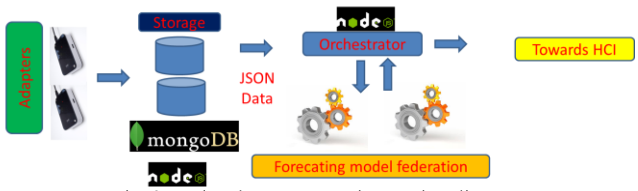

Fig. 3:Backend comopnents interaction diagram.

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IV. Sensors Network

As introduced in the architectural chapter, the SIMONA sensor network is built up by sensing modules designed to operate in different constraints scenario generated by the inherent gerarchic model of waste water transport network.

In the following we outline goal and solution adopted in this peculiar scenario.

In the SIMONA project we have foreseen the usage of low cost non contact sensors designed to operate on batteries with low mainteinance and low telecommunication network capability constraints:

Water Presence: One of the project requirements is to monitor the presence of water in overflow nodes that have to carry water only in very peculiar events (heavy rainfalls). Presence of water in normal conditions may prompt for mainteinance issues. A harsh environment water presence sensor has been developed integrating an Optical sensing solution with an ST ultra low power L series Nucleo Board and GSM Arduino compatible Board. Test results indicate the possibility to transmit SMS from underground sewage installations. The duty cycle allows for battery operation in excess of 2 years in normal conditions.

Multisensor Device: Based on a xDuino like industrial microcontroller board, a multisensor device have been developed for long term (6 Months) unattended non-contact operation. The system is devised to observe multiple variables and spot anomalous behaviours that can represent a proxy of significant variations in the quality of the sewage water. It is equipped with a microphone, a gas sensor, a remote temperature sensor, local RH and T sensor for EC calibration and an ultrasound water level sensor. In the next months the node will be equipped with the capability to detect anomalies. The node will send an SMS containing anomaly detection alert and the anomalous measurement vector.

LoadMon: An optical multisensor, the Loadmon, originally developed by the WRC, is being furtherly developed within the framework of project SIMONA. Using two powerful LED (IR: and UV:) the device capture and analyze the sewage water reflectance aiming at the determination of suspended solids (**SS**) concentration and **COD** (Chemical oxygen demand). The two indexes are currently estimated by a LUT approach. On –field recordings with a co-located commercial analyzer are on going to develop a stochastic neural calibration.

Commercial Analyzers: Low mainteinance optical sensors by S:CAN have been deployed on intermediate water pumping stations equipped with cable based internet connectivity. Water flow rate, NH3, PH, Conductivity COD and SS will be continuously monitored at 5 mins sampling period. Measured data are continuosly send to quali-quantitative forecasting and anomaly detection algorithms.

V. Data Processing Models

For the fourth architectural layer several data processing models have been devised and developed as software componets operated by the infrastructure orchestrator. In particular Quali-Quantitative forecasting are carried by using the state of the art SWMM5 framework. The model is feed by sensors data and provide insights on the water quality in several nodes of the network including the management plant inlet at three different time horizons (+2, +6, +8hrs) allowing for mitigation action to be undertaken. Simulation output are then managed by the orchestrator and shown on the HCI. The model have been developed for the demonstration site that has been chosen to be the Massalubrense (Sorrento coast, Naples, Italy) waste water network (fig. 4) and management plant. Another sought capability was the detection of anomalous sensor readings without a supervised approach. In facts, limitations on knowledge on actual local behavior of water quality parameters prevents the use of supervised learning based components. Moreover daily, weekly and seasonal cyclostationarity call for adaptation of the detector knowledge about "normal" behavior. Summarizing, due to the multi-timescale ciclostationarity and the locality of the monitored processes, anomalies cannot be defined easily. An adaptive anomaly detection algorithm have been designed in order to cope with computing resource constraints emerging from the significant incoming stream of data foreseen.

Finally a pollutant source identification algorithm (PSI) has been devised in order to identify the source of unlawful immisions by relying on the sensor readings. PSI will be actually carried out by an evolutionary programming approach (GAs). Several solutions are screened by minimizing the difference among the forecasted pollution in sensor equipped nodes and the measured water quality. The computational intensive process is carried out by relying on ENEA GRID supercomputing facilities.

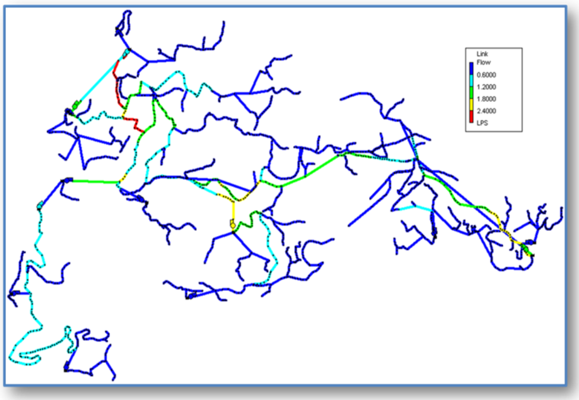

Fig. 4:Massalubrense waste water network graph with flow forecasting as outputted by the SWMM5 model.

VI. GIS HCI

Finally the last layer of the Simona architecture implements the human to computer interface capability (HCI) (fig. 5). In order to cope with the specific requests of the network operator the system has been equipped with GIS based interfaces. As previously mentioned, the GIS HCI rely, in turn, on the OGC-SWE standard framework (SensorWeb). Based on XML data exchange, the framework guarantee an open source implementation for geo-localization, monitoring, control and alerting services (SOS). The 52North application has been chosen for the implementation of the SWE framework while

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ad-hoc web pages based on the jQuery standard guarantee the web access to the provided information.

The smart GIS based HCI allow for a quick situational awareness by color coding the variables that are currently monitored on a commercial map. An ad-hoc feature allow for the export of the captured data. Results of the forecasting models are available via HCI as short videos representing the situation at the different time horizons.

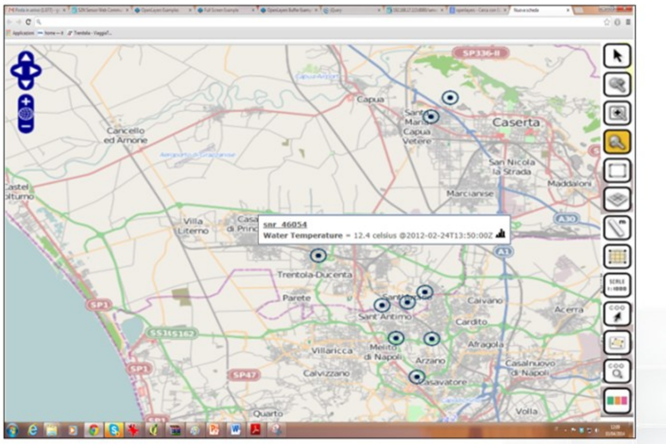

Fig. 5: An example of GIS empowered HCI screens showing the position of sensor nodes.

VII. CONCLUSIONS

Here we presented the hardware software architecture of the monitoring infrastructure of the SIMONA project devised to monitor and protect a city waste water transport network and the associated waste water management plant. Basic componets have been reviewed describing the adopted solutions in such a peculiar scenario. The SIMONA project is foreseen to start the demonstration phase including the activation of all the architectural layer by mid May 2015. The demonstration phase will last 6 months in which data will be gathered furthering the evaluation of results.

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REFERENCES

[1] Preis, A. and Ostfeld, A., (2011). Hydraulic uncertainty inclusion in water distribution systems contamination source identification. Urban Water Journal, 8(5), 267–277.

[2] L., (2008). Storm Water Management Model User’s Manual Version 5.0. EPA/600/R- 05/040, U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.

[3] OGC Reference Model, Open Geospatial Consortium Inc. ,2011 – Available at http://www.opengeospatial.org/standards/orm

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