INFRA-SEN: INTELLIGENT GEOGRAPHIC INFORMATION SYSTEM FOR REAL TIME MONITORING OF DISTRIBUTED INFRASTRUCTURES AND EQUIPMENTS IN RURAL AREAS

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Abstract

The management policy of infrastructures and equipments (e.g.: hydraulic, solar, sanitary, educational, etc.) disseminated throughout the country, particularly in rural areas, generally difficult to access, is a major challenge for the technical services of the State. The Infra-SEN intelligent Geographic Information System proposed in this paper aims to offer to organizations in charge of the management of infrastructures and equipments a platform that allows them to find out in real time how the equipments work and to detect any failures. In the present study, this paper is a contribution for analyzing the conditions of remote monitoring of hydraulic equipments.

1. Introduction

As part of the development of rural areas, the State of Senegal through national agencies and helped by NGOs has launched in rural areas a vast program of equipments in various domains like hydraulic infrastructures, schools, health and energy. However, once these infrastructures and equipments are installed, unfortunately, they do not benefit from effective monitoring despite the huge budgets invested for their implementation. This paper proposes an intelligent geographic information system for remote monitoring of distributed hydraulic infrastructures and equipments. The system proposed consists of a central server for processing measures connected to an acquisition unit that monitors a set of sensors. In section 2, we make the state of the art of remote monitoring techniques and failures detection in hydraulic installations. In section 3, the paper presents the architecture of the Infra-SEN platform. In sections 4 and 5 we successively present the approach used and the implementation of the platform, as well as the results obtained. Finally, we outline some prospects for the development of the Infra-SEN project.

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2. State of the art and positioning of our contribution

2.1 Remote monitoring of hydraulic networks

We mean by remote monitoring, the monitoring via a telecommunications network (Callens, 2016). Many methods and solutions have been proposed in the literature.
Igor's thesis works (Blindu, 2014) on the development of a model of the infrastructure management assistance tool, particularly the drinking water network of the city of Chrisinau in Moldova (1200 km of pipeline). This work has two components, namely the diagnostic aspect and the decision support aspect. The methodology developed in this work uses different tools and methods: temporal databases, spatial analysis and GIS, cognitive reasoning and hydraulic modeling of flows etc.
Blaise's works (Guépié, 2013) deals with the sequential remote monitoring of the water distribution network. The objective of this work is to study the problem of the safety of drinking water by monitoring the distribution network from the water tower to the private residences. The proposed approach is based on observation of the residual chlorine concentrations provided by the sensor network. A criterion based on minimizing the probability of detection missed providing that the false alarm rate is superior, has been used in the document. A suboptimal detection algorithm has been designed. Theoretical analysis and simulation results are provided.
In order to avoid water wastage, Isenmann and al. (Isenmann et al., 2016) worked on the evaluation of the discharge from the overflow of a pumping station by the measurement of water heights. This work describes a calculation method that establishes the relationship between the water level above the base of a pump station overflow pipe and the flow discharged. The tables height/debit constructed can then be implemented in transmitters or interpolated for post processing.
Karim and al. (Karim et al., 2016) propose an approach to pre-localize physical losses on a drinking water distribution network by optimizing the hydraulic model via an evolutionary algorithm, to pre-localize areas with high leakage debit. Their approach is based on the resolution of the FAVAD (Fixed and Variable Area Discharge) equation by optimizing its parameters (coefficients and exponent of the transmitter) via the use of Genetic Algorithms (GA) coupled to an interfaced hydraulic modelling with a Geographic Information System (GIS). Cheifetz's work (Cheifetz et al., 2017) proposes a greedy algorithm for the positioning of quality sensors on a large water distribution network. This approach uses a large number of contaminations, simulated by a hydraulic modeling software and iteratively selects the best positions according to a criterion set to optimize. The method is evaluated for the deployment of multi-parameter sensors measuring chlorine, temperature, pressure and conductivity on the network of the Water Authority of Ile-France (Sedif), the largest French drinking water distribution network.
In all cases, remote monitoring is not used as a warning system but aims to adapt the treatment according to the values found on the measured parameters (Dary, 2014). It only makes it possible to detect failures without necessarily geolocating faulty equipment. Except in the case of a central system where all the equipments

is on a single site, the location of the failed equipment is already known. In our case, we are interested in equipment distributed on the territory, where the need to geolocate them with a GIS in case of occurrence of failures (multi-site remote monitoring system).

2.2 The detection of failures related to leaks

The exploitation of drinking water distribution networks around the world suffers from numerous failures that can arise in arbitrary places that are difficult to determine. In addition to the enormous economic losses bound with faults, there is also the risk of epidemics caused by leaks that constitute a great danger to public health. A study conducted by the International Association of Water Distribution (IAWD) shows that the amount of water lost through the distribution networks would be between 20% and 30% of total production. This has led network operators to think of using more efficient ways to detect these leaks in record time. In the field of leak detection, there are several methods and techniques. Currently used detectors can be classified into two main categories:

- acoustic noise-based detectors that require the operator to move to locate the exact location of these leaks and acoustic correlation based detectors that allow remote leak detection, and which give the place of escape with great precision.

- acoustic correlation detectors are used to detect leaks. Indeed, this technique is the subject of several works and implementations.

It is used for leak detection by Osama (Hunaidi, 2000). In the works of Miloud (Bentoumi et al., 2007), this same method was used to implement a leak detection algorithm in distribution networks on the TMS320C6201 processor. The National Directorate of Drinking Water and Sanitation of Haiti (Dnepa, 2013) in its document entitled “Control of water loss leak detection” has used the acoustic correlation method for precise location of leaks. In the works cited, formulas, algorithms and architecture have been proposed for the detection of leaks. But, these works apply only to metal tubes.
The method of acoustic correlation, although effective, finds its limits. The acoustic method becomes problematic in the case of plastic tubes (Hunaidi, 2012). The acoustic leak detection equipment was designed primarily for small diameter metal pipes. However, the signals emitted by the leaks in the plastic tubes have acoustic characteristics that are substantially different from those produced by leaks in metal pipes. Materials such as HDPE or PVC absorb vibrations enormously. A recent study conducted by the Canadian Institute for Research on Construction (IRC) and funded by the American Water Works Research Foundation found that leaks in plastic tubes can be detected using acoustic techniques, but that presents many difficulties.

2.3 Positioning of our contribution

However, in Senegal plastic tubes are the most used in water pipes, it would be more effective to use non-acoustic techniques for leak detection.

Leaks in plastic tubes can also be detected using non-acoustic techniques such as tracer gas, infrared imaging and radar. However, the use of these techniques is still very limited and their effectiveness is not as well established as in the case of acoustic methods (Hunaidi, 2012).

3. Infra-SEN Platform architecture

The general objective of our work is to design an Infra-SEN platform for remote monitoring of distributed infrastructures and equipments. This equipment have been instrumented with sensors capable of acquiring measurements. The sensors must deliver measurements that are recorded by an acquisition system. The installations to follow being positioned in different localities (distributed), to find the locality of the defective equipment we will exploit the spatial analysis capabilities of the ArcGIS software. Thus, maintenance teams can be informed about the locality where they will have to intervene to restore the proper functioning of the installation. Equipment likely to fail will be connected to one or more sensors that deliver information on the operation of this equipment. This information dynamically feeds the Infra-SEN database, which is linked to the ArcGis database. Using ArcGIS' spatial analyst, we can reference and map all equipment including their failures.

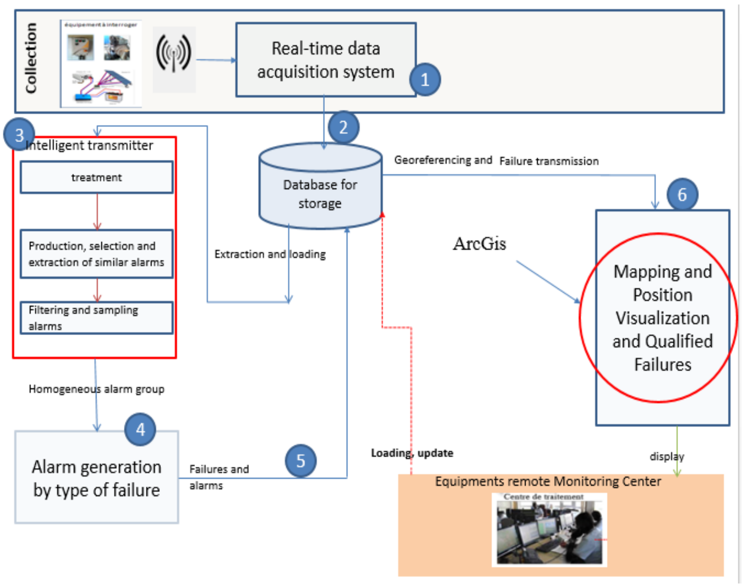

Figure 1: Core architecture of the SIGI platform

4. Description of our method for failures detection

We use the technique based on the measurement of the debit of water. In this method, we calculate the variation of the debit between two measurements and the Linear Leakage Index (LLI). A good approach to this index is obtained by measuring the minimum night debit (usually between 1 am and 4 am, after deduction of heavy nocturnal consumers (Dnepa, 2013)). It is calculated in this way.

LLI= Volume lost in distribution (m3/j)/ length of the pipeline (km) (1)
Volume lost in distribution (water lost)= volume put in distribution – volumes consumed.

We will retain as guide value:
Rural area LLI ~ =2 m3/j/km
Peri-urban area LLI ~ = 5 m3/j/km
Urban area LLI ~ = 10 m3/j/km

Areas with significant leakage can be determined by the method of test by step. This consists of subdividing the sector and then measuring the debit. Balance sheets by sector require a lot of work because they are done at night. In recent years, there has been a tendency to permanently install flow sensors connected to the system. The values of the debit thus transmitted are automatically analyzed and allow detecting the leaks.

4.1 Module Infra-SEN for failure detection related of leaks debit

This module uses the following algorithm as a technique based on the treatment of measuring the debit of water to detect leaks.
The primary state quantity, which one wishes to control the value, is the debit level. The objective is to obtain measured flow rate (M) equal to its normal debit (C). If M is not equal to C, we will have M= C- e, with e difference between measurement signal and normal debit. To establish this algorithm, we based ourselves on the method of the straight line of linearity. When two quantities are such that the variations of one are proportional to the variations of the other, then the values y of one express themselves according to the values x of the other by a relation of the type y=ax+b, where a and b are two real numbers. Given a straight line, we consider on this line a fixed point, final measurement Mf (xf, yf) and an arbitrary point Mi (xi, yi). According to the properties of similar triangles, the quotient (yf- yi)/ (xf- xi) does not depend on the point Mi chosen on the right, so this quotient is equal to a constant. This constant a is called the steering coefficient (or slope) of the line; (yf- yi)/ (xf- xi) = a.
The steering coefficient gives the direction of the right. In our practical case, the steering coefficient indicates the debit of water. In fact, in both cases, y varies by the same quantity $\Delta y = a\Delta x$. We will hold back the writing $a = \Delta y/\Delta x$. Three cases possible:
If a>0, so y increases when x increases (the function is increasing). y increases all the more rapidly as a is large. The suction cups are poorly closed and the air that enters increases the output debit.
If a<0, so y decreases when x decreases (the function decreases). y decreases all the more rapidly as the absolute value of x is large. There is a leak in the network, this justifies that the output debit is lower than the input debit.
If a=0, so y is constant, so the debit measured by the different sensors is the same.

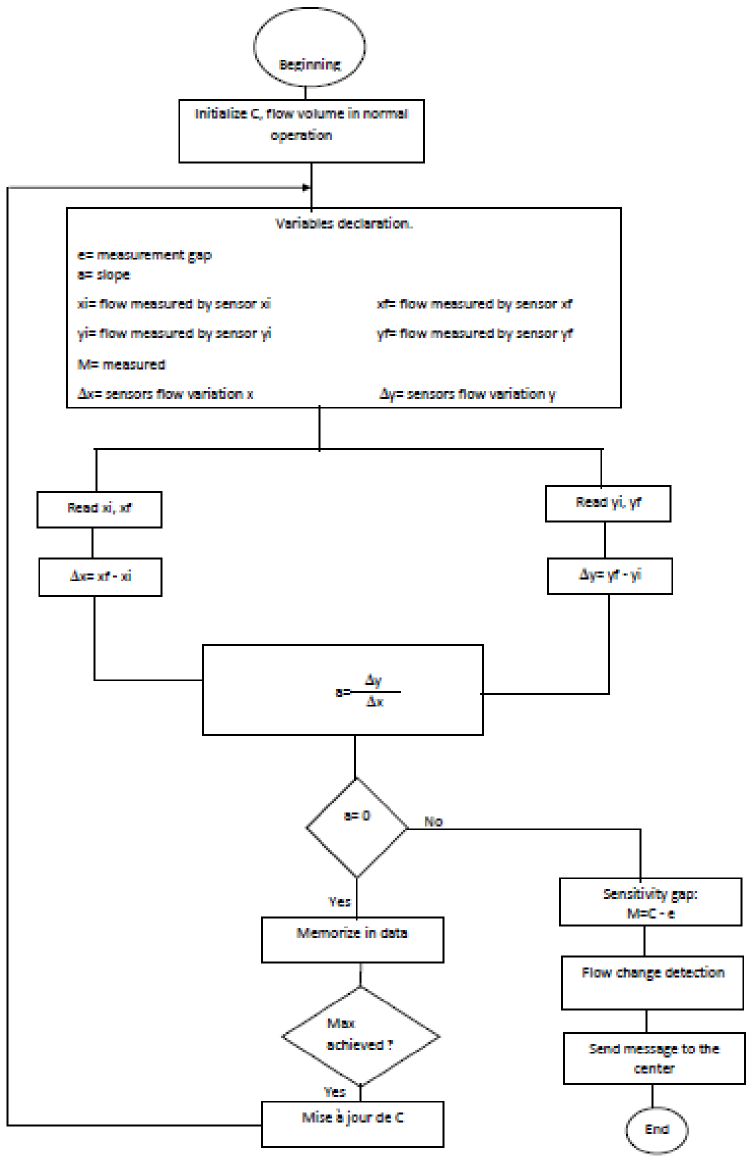

Figure 2: Algorithm of measurement processing to detect leaks

5. Implementation of the Infra SEN platform

The implementation of our platform is designed as a client-server application and it is based on the 3/3 architecture. In such architecture, the application is composed by three parts. The first third (1/3) is the application server that allows the processing of data. The application server contains our application who can write to the database, to record the measurements of different sensors to modify the elements of the table. But also the ArcGis application that includes the cartography modules, exploitation and viewing data. The second third (2/3) is the data server who allows data storage. It includes the ArcGis database and the Infra-SEN application database we have developed. The third (3/3) are the customers (Users) who will access the applications and use data. Below the operation of Infra SEN (Figure 3):

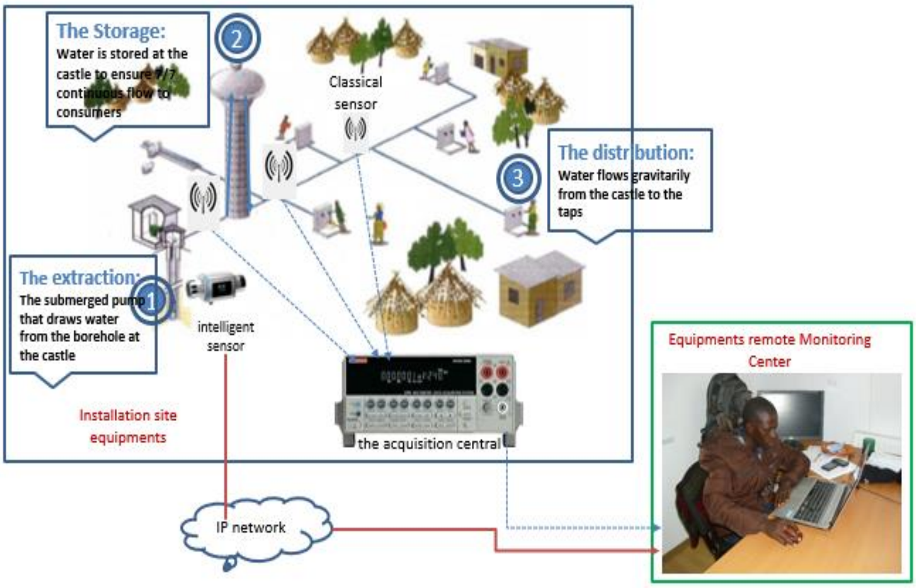

Figure 3: Operation the Infra SEN platform

For data acquisition by sensors, we use classical sensors who send the message to the monitoring center via the acquisition central. For each installation, we target a critical equipment that will be connected by an intelligent sensor. In our example, it is the submerged pump. For this object, it is the technology of the Internet of connected objects that will be use to communicate with the central remote monitoring station.

6. Deployment of the infra-SEN platform

Failing to have physical installations, we used the Scilab numerical analysis software to simulate the measurements acquisition. In the case of a physical installation, the procedure and algorithms remain unchanged.

Scilab, is a free multi-domain simulation software that provides a graphical platform and a set of libraries that allow modeling, simulation, the implementation and control of systems in different areas of application.

To simulate, we need a description of the program. In the execution of this program, we have respected the various stages of operation of the central. The time step is managed by the multithreads programming technique. We used the function rand (n, m) which automatically generates values that simulate measurement sensors outputs as a function of time. n is the measurement time and m, the measurement output of the sensors. The thread function Sleep (z) is used to manage the time step. This allows to asleep the program for a desired time Z. Every day measurements are made. The total number of experiments is 100 days. Every hour the sensors send measurements to the acquisition central. We present the results in Figure 4.

1.	43.11733	72.174381	52.641283	74.444567
2.	61.453848	47.685359	52.973941	22.695036
3.	92.589621	63.930579	92.917561	68.369308
4.	9.9381728	99.638653	97.654303	93.650726
5.	42.805786	15.747883	62.25464	50.530174
6.	94.31831	53.506937	98.225833	25.248146
7.	3.2739527	21.290646	75.429888	68.188398
8.	92.132671	55.914506	54.547881	28.363682
9.	94.490244	43.04966	72.86016	14.094857
10.	90.070699	2.2805485	2.5259695	67.591096
11.	80.943161	57.614598	40.251685	45.126776
12.	2.5195429	71.491304	9.8313199	75.430292
13.	0.1964506	93.21636	26.086253	13.702143
14.	50.752213	12.326993	36.363423	66.082405
15.	40.76043	28.655522	17.466178	38.900542
16.	84.080461	1.2479957	92.341395	70.018205
17.	50.172657	57.694048	76.051409	91.680057
18.	91.287808	39.386961	56.402041	21.229
19.	44.357295	68.885837	37.970652	26.978331
20.	59.83784	97.023218	87.762262	31.998894
21.	77.418426	85.157643	82.174258	2.3218025
22.	79.220083	33.933045	67.870581	72.654473
23.	55.046049	87.725318	8.2200981	15.340586
24.	40.850437	11.314025	25.527314	23.552638

Figure 4: Results of measurement values by sensors during a day

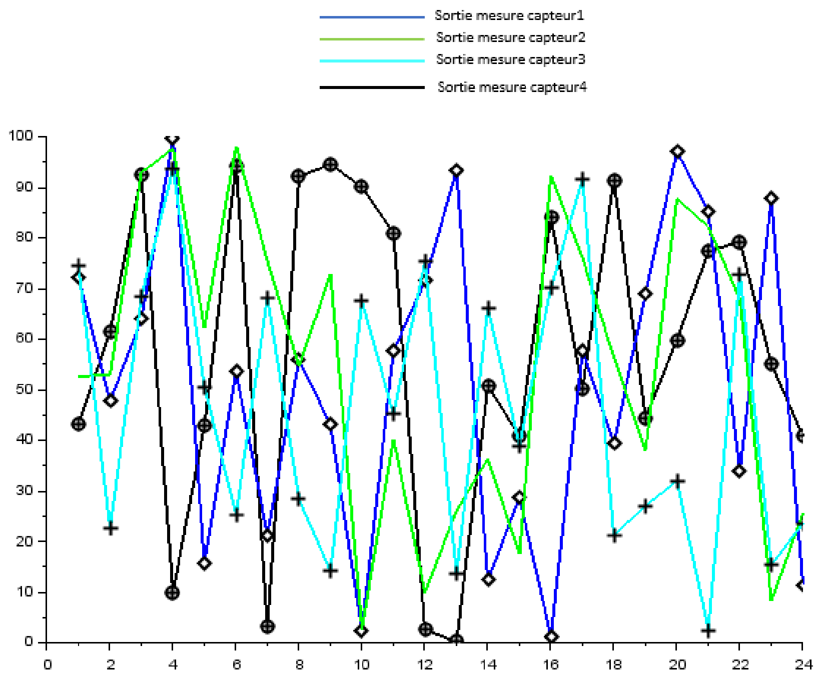

Figure 5: sensor measurements versus the time.

The generated values will be saved to a file and retrieved by a java program. After executing the code, the program displays all the measurements including those that present leak (Figure 6).

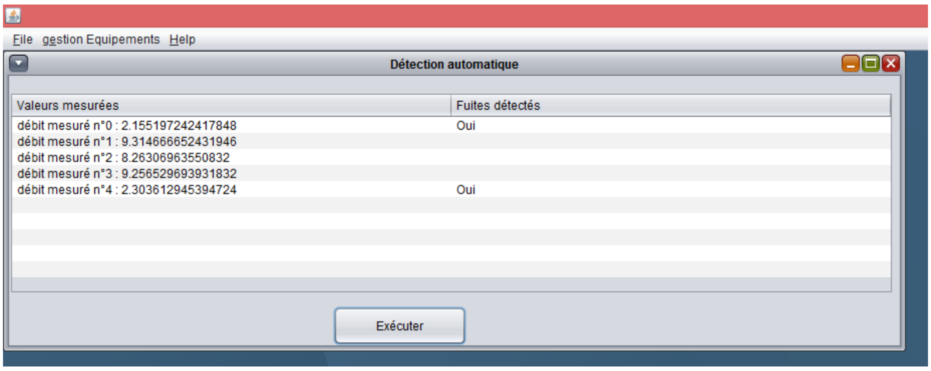

Figure 6: Zoom on the measured values and leaks detected in the Infra Sen application.

These values will also be saved in the Infra SEN database in the measurement table. Indeed, once the failures are detected, ArcGis features are triggered automatically to produce the equipment cards that present failure.

7. Conclusion and perspectives

In this paper, we propose a real-time remote remote equipment monitoring system based on a GIS. This system is efficient and requires fewer resources than those found in the literature. This system significantly improves the quality of service; reduces wasted time and costs related to equipments maintenance. However, if the system proposed allows remote monitoring of the equipment, it does not yet solve the problem of maintenance to remote. This falls under the problematic of remote maintenance that we have not discussed here. The application to the monitoring of hydraulic equipment in the municipality of Niamone in the department of Bignona validated the mapping and algorithmic aspect of failure detection. Future work should allow us to perform full-scale tests for the whole territory. Based on the Infra-SEN project approach, many remote monitoring applications are possible, in the health sectors, education, renewable energies including solar panels.

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