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Sensor based Leak Detection in Urban Water Supply Systems on the example of the drinking water distribution network of the city of Darkhan, Mongolia

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ABSTRACT

Fraunhofer AST takes part at an IWRM (Integrated Water Resource Management) project in Mongolia [3]. In the city of Darkhan, the largest city in the project area, the water loss in the drinking water network is about 40% of the fed in water. Leak positions are unknown yet. The use of correlators is difficult because the pipes are installed very deep into the ground. The intention of the project is to install a pre-defined amount of combined pressure-/flow-/noise-sensors at selected nodes in the supply network to The estimate the position of the leaks by online measurement of different network parameters. Network inflow from tanks and network outflow (consumer demands, leakages) produces a typical pattern of dynamic pressure on each network node caused by the head loss in the pipes. Because the consumer demand will change with a typical profile during the day and the leak flow depends on the nets pressure it is possible to estimate the position of leaks by using genetic optimization algorithms in combination with a hydraulic simulation using the software tool HydroDyn.

Index Terms – combined sensors, leak detection, genetic algorithms

1. INTRODUCTION

Leakages and the water loss caused by them are one of the most important problems in urban water distribution systems. Press reports that suggest over 50% of carefully-treated water put into distribution is lost on its way to the tap are certainly cause for alarm. Because of its high figures involved, this lost water is often called 'the second water source'.

Water supply networks are located below the ground and this makes it often very difficult to detect leakages. Only large leaks generates emerge through the ground. Currently leak detection often happens manually by pacing off the pipes and listening to the typical noise produced by leakages. Therefore one has to know the approximate position of the leak. Another method to detect the leak position on one single pipe is the use of acoustic correlators. The third method described in some papers in the past is a combination of hydraulic simulation and online pressure measurement. To find the leak locations Genetic Algorithms will be used. The disadvantage of this approach is the requirement of an very well calibrated hydraulic model, the knowledge of exact demand profiles as well as very accurate pressure and flow measurements that often are unavailable.

2. THE MODEL REGION

In the IWRM Project "MoMo" (Integrated Water Resource Management in Model Region Mongolia" Fraunhofer AST has to analyze all aspects of sanitary environmental engineering and drinking water supply in the model region.

The city of Darkhan is situated in northern Mongolia about 250km away from the capitol Ulaanbataar. The local water distribution company USAG supplies 90.000 inhabitants with an amount of 21.000m³/d of water, produced by 18 wells near the river Kharaa. Water quality is no critical problem in the region yet but the state of the network. It was built in the early sixties of the past century. 21 old pumps are installed in two pumping stations. On the top of a hill, about 100m above the city, a system of four large tanks with a volume of 16.000m³ is located. From there the network is supplied without any additional pump only by the hydraulic head produced in the tanks. The only network parameters that are measured online are the state of the pumps (on or off) and the flow from the tanks into the city. Nearly 50% of the income from water charges is used to cover the electrical consumption of the pumps and other electrical equipments. Because there are only 5% of households equipped with water meters currently a program to install a water meter in each household was started by the supplier.

By comparison of some manual measurements in the first project phase of "MoMo" (amount of water pumped into the network and online measurements from some industrial demands), a water balance sheet was developed. One could see that the amount of leakage in the network of Darkhan is more than 40%. This means that 40% more water than need is fed into the network, the amount of pump energy needs is therefore also 40% higher than needed. So in the converse argument one can say that a reduction of the water losses to an amount of 10% can save energy and water extracted from the groundwater by about 30%. But there is not only the save of energy and water. With the reduction of electrical energy consumption the bill to pay to the electrical company will be reduced dramatically. So the water supply company will have a lot more money available for further investments like network rehabilitation. Nearly 65 % of the pipes are damaged or do not meet modern technical requirements. Therefore in the second project phase of “MoMo” a leak detection system shall be installed.

3. THE LEAK LOCATION PROBLEM

The overall pipe length of the network in Darkhan is about 215km and most of the pipes were run more than 3 below the ground. This is necessary because of the semi-arid climate in Mongolia. In the summer the temperatures may raise up to 38°C and in the winter often temperature falls below -40°C. From November to March the ground will be frozen to a depth of about two meters. But these deep laying pipes make it difficult to detect leaks with conventional techniques because the pipes are not accessible for many months to use correlators or geophones. Also when leaks occur the water flowing out of them will not break through the ground. The frozen ground avoids this and water often flows into the groundwater layer.

But also in cities in Europe leak detection with acoustic methods will be done only if there is a reasonable suspicion. If a SCADA is available and some online measurements are done in the network a raise in the demand over night hours will give first indications for leakages. Often the amount of the leakage flow can be estimated if a well calibrates hydraulic model of the network is available. To get such a well calibrated model there are a lot and long term measurements within the network necessary. If the model is calibrated an approximate leak location can be done with the use of Genetic Algorithms [1].

An approach often used is to divide the whole network into separate zones where the inflow of each zone is measured continuously. These zones are called district metered areas (DMA’s). The leak detection in such network is easier because the area where the leak is located can is only as large as the DMA. Often leak detection will be done rotational in defined intervals (e.g. once a year). A trend in raising flow between the measurements can be a good indication for the presence of leakages. But the time between the occurrence of a leak and its detection at a measurement can be very long. Depending on the size of the leak the disprofit for the supplies may be enormous. So an immediate and reliable record of water losses and clear identification of leak zones through permanent monitoring provide huge potential for savings, as these actions would minimize the duration of water loss and considerable reduce the effort required to detect leaks.

Alongside the well-known leak detection and applied water loss analysis tools, there is a need for a tool able to observe and monitor the whole pipe network to enable sustainable water loss management. To detect leaks just in time it is essential to have an online monitoring system that is capable to measure parameter that changes in the moment when a leak occurs. The needed parameters to do that are the noise generated by the leak, the pressure change and the flow change. When a leak occurs then the noise level will raise dramatically with a typical profile. After some hours the noise level will drop to a lower amount and after some days there is no hint for a leakage in the noise measurements. The occurrence of a leakage can also cause a flow direction change or a head loss around its location. Combining measurements of these three parameters can make an improvement in leak detection.

4. THE USED SENSORS

The sensors that will be installed in the network of Darkhan will be the WLM-Sensor of Martinek Water Management GmbH from Austria [2]. These sensors can measure all the needed parameters at once an where developed with the goal of easy installation, high accuracy and easy handling.

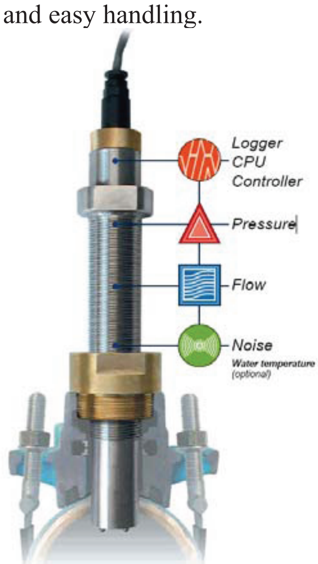

Figure 1

Another important feature of the maintenance free WLM-sensor is the integrated electronics. The electronics package includes all of the necessary control elements for the sensor as well as a logger for data storage. A CPU calculates the significant values for each parameter measured and manages the communication to the central computer. The communication between each sensor and the central computer can be done either via cable or GSM modem. A SCADA System is not necessary for the operation of the WLM sensor system and so this system is well suited to be installed in networks in emerging or developing countries. The collected data are stored in a database where other Software can access.

5. THE WORKING PRINCIPLE

The sensors will be placed in the network and divides it into virtual measuring zones (see Figure 2). The sensor measures all three parameters (flow, pressure, noise) simultaneous in the network. The magnetic inductive flow sensor is desired to measure very low flow speeds form 0.01m/s (up to 10m/s) with a resolution of 1mm. Accurate measurements are possible and will be used for hydraulic model calibration, but for the leak detection they are not really necessary. It is important to focus on comparing the measurements from the current day with previous values. The sensor fit calculated boundary values with each new measurement automatically and use them for the leak detection. An integrated piezo-ceramic pressure sensor has a range from 0 to 200m and measures the dynamic pressure in the network as well as performing data acquisition for analysis. A highly-sensitive microphone also integrated which performs a similar function to a noise logger. The key advantage is the positioning in an area well protected from surrounding noise and with direct connection to the water. This allows relatively good detection of typical leak noise not only via the pipe material but also through the water column. The flow noise recording provides valuable data for analysis. The interaction between the parameters and the automatically calculated boundary values produces a very accurate picture of where leakage is occurring. If a sensor highlights a flow alarm and no indication of leak noise, it is probably out of the noise detection radius of the sensor [Figure 2]. In general, for pinpointing the leak, traditional methods should still be applied.

All the data coming from the sensors will be stored in a database where other tools can access it. When a leak come up the noise level will raise in a typical way. Also a change in flow (fluctuations and sometimes direction changes) and a slight pressure drop can be measured [Figure 3]. These changes will be detected by “Aqualys” Software and an error message will be created. Depending on the values of the three measured parameters the approximate distance and the direction to the leak can be estimated via the noise level and the amount of flow change and pressure drop. In normal operation the measured parameters stored in the database will be used in combination with Fraunhofer Software “HydroDyn” for evaluating the capacity, that is, the condition of the pipe network. “HydroDyn” is a tool for planning, simulating, and optimizing pressurized water networks, gas networks and sewer systems. Normally the after the acquisition of a network in a hydraulic simulation software a model calibration will be done once to match the model to the real world. With extensive field measurements the model can be calibrated [5]. This calibrated model is now valid for the actual date. The system described in this paper

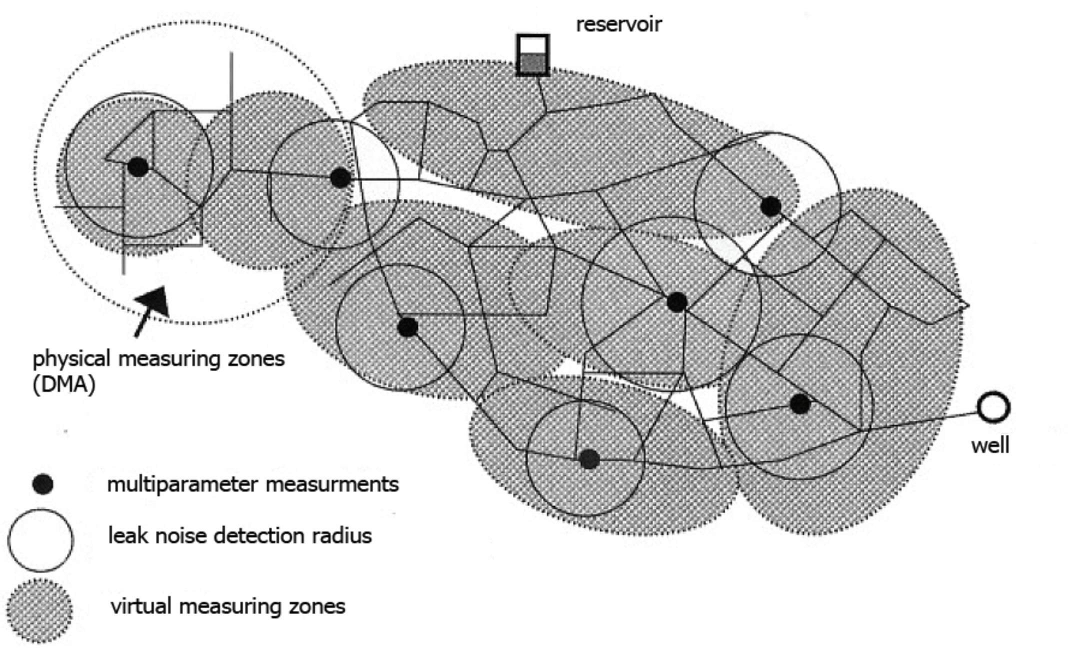

Figure 2

does more. The model calibration will be done continuously in a configurable interval (e.g. one month) with the collected data from the sensors in "HydroDyn". This can be called "floating calibration". What is the advantage of this? Normally network parameter and therefore network hydraulics changes slowly over time. The sensors provide only data from the current state of the network but they will do this continuously. By collecting these measurements in a database and analyzing data over long periods (months or years) slow changes in network parameters and effects like pipe aging, blinding of pipes or changes in customers demand behavior can be detected. So the model continuously will be adapted to the real system by changing the model parameter (e.g. roughness values, customer demand profiles) to match the measured values. This gives also the advantage to detect trends in development of the network state and predict upcoming bottlenecks in supply. Also remedial actions can be planned with these trends.

When "Aqualys" detects a leak then "HydroDyn" with its up to date model is able to calculate the leak position using measured and simulated data in combination with Genetic Algorithms. The method used is not new and was described in some papers in the past [6]. The described method has some disadvantages. As can be seen in [Figure 3] the network parameters will be nearly in the pre-leakage range after some hours after leak appearance. Especially at small leaks this will be happen very fast. After that time there is nearly no indication in the sensor data that gives a hint of a leak. Only a lot of small leaks or a large leak will give significant parameter changes over a long time and only such leaks can be detected with sporadic measurements. The combination of the WLM-sensor, "Aqualys" and the Genetic Algorithm in "HydroDyn" now gives a lot of advantages. When a leak comes up network parameter will change just in time. In difference to [6] the available information are more accurate and will be used to isolate leak search area. Therefore the optimization problem will be reduced dramatically which gives a better algorithm performance. With the knowledge of the data from the sensors the boundary conditions of the genetic algorithm can be adjusted in that way that a faster convergence can be reached.

6. FURTHER DEVELOPMENT

The noise sensor integrated in the WLM measures only the noise level and the software calculates the distance to the leak from the measured parameters. This is an estimation which is not as accurate as the measurement with correlators.

To increase the accuracy the idea for further researches is to use the principle of acoustic wave front measurements like done in correlators in meshed networks. An acoustic wave propagates through the network with a specific celerity that depends on different factors like pipe material, soil conditions, water temperature and flow direction. A lot of this information and also the network topology (network graph) are available in "HydroDyn". If it would be possible to measure the time that wave front needs to reach a sensor in the network it will be possible with at least three sensors to calculate the exact position of each leak within the network.

Another, similar approach for leak detection is the observation of transients in water networks [4]. The last both methods need special sensors that are capable to measure the wave front of the noise or the pressure wave through the pipe.

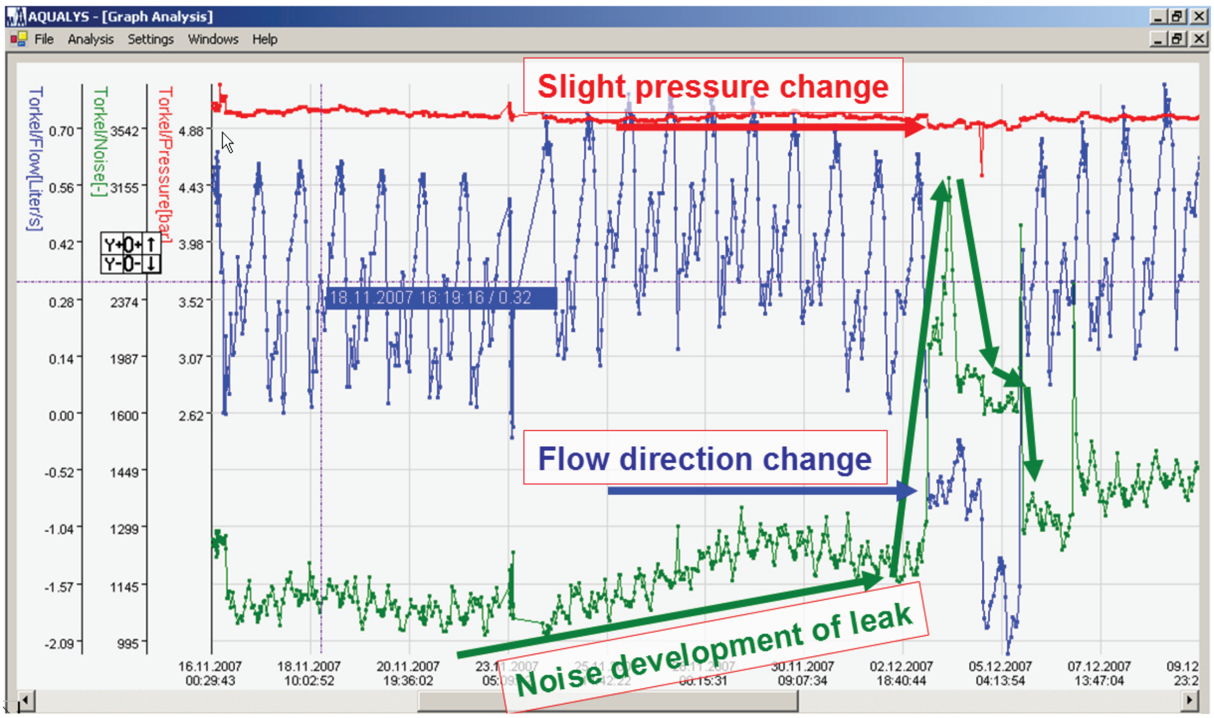

Figure 3

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