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EARNPIPE : A Testbed for Smart Water Pipeline Monitoring using Wireless Sensor Network

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Abstract

Large quantities of water are wasted daily due to leakages in pipelines. In order to decrease this waste and preserve water, advanced systems could be used. In this context, a Wireless Sensor Network (WSN) is increasingly required to optimize the reliability of the inspection and improve the accuracy of the water pipeline monitoring. A WSN solution is proposed in this paper with a view to detecting and locating leaks for long distance pipelines. It combines powerful leak detection and localization algorithms and an efficient wireless sensor node System on Chip (SoC) architecture. In fact, a novel hybrid Water Pipeline Monitoring (WPM) method has been proposed using Leak detection Predictive Kalman Filter (LPKF) and Modified Time Difference of Arrival (TDOA) method based on pressure measurements. The data collected from sensors are filtered, analyzed and compressed with the same Kalman Filter (KF) based algorithm instead of using various algorithms that deeply damage the battery of the node. The local low power pre-processing is efficient to save the power of the sensor nodes. Moreover, a laboratory testbed has been constructed using plumbing components and validated by an ARM-based prototyping platform with pressure sensors.

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Keywords: Water Pipeline Monitoring; Wireless Sensor Network; Kalman Filter; System on Chip;

1. Introduction

Water is a vital source of life in the earth. Up to 60% of water is wasted every year due to leaky pipes generating economical, environmental and possible human losses[1]. This is contributes as a major factor in water crisis all over the world. In fact, according to a new study published by Science Advances newspaper in February 2016, approximately, four billion people all over the world are facing water scarcity[2].
Hence, these alarming statistics make water preservation as a fundamental issue to maintain human life by controlling pipes transporting fresh water.

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Countless leak detection and localization techniques for Water Pipeline Monitoring (WPM) are reported in the literature[3,4]. The classical methods are periodic and non technical. Experienced personnel are patrolling along the pipes looking for visual leaks or using equipments (like acoustic/ultrasound) to search anomalies. This kind of methods is painful and affected by the staff experience. Moreover, it could not be continuous and useful for inaccessible pipes. In the following, we do not consider these methods.
WPM systems are practically based on two main steps: the sensors/equipments used to collect useful information and the way to process and to analyze this information.
In fact, the sensors could be just placed on key points of the pipeline (inlet, outlet) or installed along the pipe using wired or wireless technology[5]. Wired networks have various drawbacks including the cost of installation and maintenance. Besides, a damage in a wire could alter the whole network. Recent researches have highlight the importance, performance and reliability of Wireless sensor network (WSN) in detecting and locating leaks during the last few years. It is characterized by its continuous inspection and real time monitoring[6].
On the other half of the deal, various methods have been employed to analyze data collected from the sensors. They could be divided into signal processing methods, knowledge based methods and model based approaches.
The signal processing methods are based on the signal analysis and interpretation in the time or the frequency domain[7]. Methods based on knowledge like support vector machine (SVM), pattern recognition and expert system are also extensively tested[8].
Model based approaches use in general conservation of momentum, conservation of mass or conservation of energy to build a model and predict the leaks presence. In these techniques, Kalman Filter(KF) is widely applied in its linear and extended form thanks to its low complexity and small memory requirements[9]. The variety of techniques and the continuous efforts in this fields is due noisy and variant pipe environment. Searching for optimal and accurate solutions still an open research axis.
In this context, we introduce a first prototype of EARNPIPE: Energy Aware Reconfigurable sensor Node for water PIPEline monitoring. A reliable solution for inspecting pipe infrastructure. We propose a complete WSN solution coupled with Leak detection Predictive Kalman Filter (LPKF) and other methods to detect and locate leaks.The use of WSN in junction with KF permits to benefit from their advantages, enhance the accuracy of the leak detection by avoiding false alarm and optimize the power consumption of the node and the network. This proposal combines high-performance platform and powerful mathematical non-destructive inspection methods using pressure measurements.
The paper is organized as follows. Section 2 itemizes the related WSN projects used for WPM application (WSN-WPM). A detailed description of EARNPIPE prototype in terms of network architecture, sensor node architecture, equipments and leak detection algorithm will be given in the section 3. In section 4, We explain the experimental setup and the results. We finish our work with conclusions and perspectives in section 5.

2. Exploration of WPM projects using WSNs

WPM has benefited from the WSN progress. The migration to WSN is due to is potential. A typical network consists of a large number of sensor nodes, which are densely deployed to collect and transmit data via wireless connections to inspect physical quantities and environmental conditions.
Various WSN projects exist in the literature[10,11] focusing in different aspects including efficient node communication along the pipe, the placement and replacement of nodes, etc. We review below some projects:

PipeNet[12] is a well-known project for WPM developed by imperial college, Intel, and MIT in 2007. Acoustic/vibration and pressure sensors operates to detect and locate leaks. The adopted node is based on Intel commercial mote composed of an ARM7 core, a 64KB RAM, a 512 KB Flash, and a Bluetooth communication. Algorithms like WT, cross correlation and pattern recognition algorithm, have been also implemented to process the sensors data. Although this work gives a complete solution for WPM, two significant drawbacks could be mentioned. Firstly, several high processing algorithms are employed which affect the power consumption of the nodes by accomplishing complex tasks. Secondly, the authors collect data with a very high sampling rate and high frequency. Even this make the solution real time, it also act on the increase of energy consumption of the node.

Kim *et al.* propose Nonintrusive Autonomous Water Monitoring System (NAWMS) allowing auto-calibration of water system and computing the quantity of used water by using flow meter and vibration sensors attached to the pipeline. A mixed linear geometric model is proposed for data calibration. The system is dedicated for houses to