Pipeline Monitoring System Using Wireless Sensing Network

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ABSTRACT: A water pipe is any pipe or tube intended to carry drinking water for consumers from one place to another without any losses. Leaks and breaks in pipelines and blockages in water supply sewer collector overflow events cost millions of dollars a year, and supervision and repair of this underground infrastructure. This paper present a unique in-pipe water monitoring and feedback system with a human centric cyber physical framework architecture. This system includes the physical water distribution infrastructure, and intelligent agents supported by hardware and software for water allocation, leak detection and spread control of contamination. An agent-based approach is chosen for connecting cyber and physical layers, where agents receive information from sensors monitoring the physical components and provide the cyber system with this information. The Hidden Markov Models (HMM) are briefly explored in order to assess patterns of water use and make decisions about cyber and physical systems.

KEYWORDS: Wireless Sensor Networks, Pipeline Monitoring, Water Supply Systems, Intel Mote Platforms.

INTRODUCTION

A water pipe is any pipe or tube intended to carry drinking water for consumers. Depends on the context, if the water is treated before distribution or at the point of use (POU). Water is usually handled before delivery in well-planned and constructed water distribution networks, and often chlorinated as well, to prevent recontamination on the way to the end user. The water pipe types include large diameter main pipes, supplying entire cities, smaller branch lines supplying a street or group of buildings, or small diameter pipes within individual buildings. Water pipes can vary in size from massive mains with a diameter of up to 3.59 m to small 13.0 mm pipes used to feed individual outlets inside a house. Materials which are commonly used to build water pipes include polyvinyl chloride (PVC)[1], cast iron, copper, steel and concrete or fired clay in older systems. It is possible to connect individual water pipe lengths with flange, nipple, compression or soldered joints to form extended runs.

Pipes come in various sizes and types. They can be divided into three main categories: metal pipes, cement pipes and pipes made of plastic. Includes steel pipes, galvanized iron pipes and cast iron pipes. Cement pipes include cement pipes made of concrete and cement pipes made from asbestos. Plastic pipes include polyvinyl chloride (PVC) plasticized pipes

Indian water companies are under growing pressure to strengthen their aging asset management and maximize operational and capital spending. A new report by the US Environmental Protection Agency (EPA) reports that over the next 20 years (2003-2023) water systems need $300 billion to build, upgrade and repair facilities. Transmission and distribution projects account for the largest portion of this calculation ($184 billion). The possibility of contaminant contamination as a result of leakage of pipes or malicious human activity would further increase the expected costs[2].

Repairing and maintaining this infrastructure requires significant expenditure of money and resources, so concerted efforts to repair critical areas are necessary. Unfortunately, it is a non-trivial job to classify the highest priority areas, due to the size and age of the pipeline network and lack of operational data. Since these are supply critical systems, failures of broad diameter (12 "and greater) bulk-water transmission pipelines are of greatest concern[3].

Although these incidents are infrequent, they have devastating consequences when they occur, including loss of life, serious service interruptions, impaired firefighting capacity, damage to adjacent facilities and structures, and multi-million - dollar bills for repair.

In this paper, Pipe Net is explained, a wireless sensor network-based device that aims to track, locate and measure bursts and leaks and other anomalies in water delivery pipelines such as blockages or malfunctioning control valves. The system is also used in transmission and distribution water systems for controlling the water quality and tracking the water level in sewage collectors. This paper developed a Pipe Net in stages, since building such a monitoring system with many unknowns is a complex problem. In this paper Author present findings from the first two stages, during which it is evaluated that some of Pipe Net's critical components through a real deployment (Stage 1), and built a set of algorithms to detect and locate the exact location of the leaks that are tested under laboratory conditions (Stage 2)[4].

Operational pipelines are subject to complex, highly non-linear temporal and spatial processes which render distinguishing between faults and stochastic system behaviors difficult. This makes identification of failures a difficult task, leading us to a solution focused on the integration of remotely collected data from multiple sources including: acoustic / vibration signals, velocity (flow) signals, and transient pressure signals. Acoustic / vibration signals are used to detect minor leaks that may be precursors to disastrous bursts, while the study of transient pressure and velocity (flow) allows for the timely detection and localization of larger leaks and malfunctioning equipment such as air valves[5].

In a previous study tracking operational transmission mains, and successfully demonstrated that synchronized pressure and velocity (flow) data from multiple locations along a pipeline could be used to detect medium to large size leaks and malfunctioning equipment continuously acquired over time. This proof-of-concept was performed by storing sensor readings on a PC-104 embedded PC with CompactFlash. Readings were manually collected and offline analyzed.

Therefore, Pipe Net is the next generation Intel Motes-based device that fixes the shortcomings of this past work; it includes near-real-time remote control, variable sampling rate and long battery lifetime. Pipe Net also facilitates the coordinated data collection from multiple locations for high data rate time. Conversely, the current method of data collection within the water industry depends on portable loggers and a small number of remote monitoring stations with a low-duty duration. These remote monitoring stations do not have the capabilities to obtain high data rate, local processing, or transmit high bandwidth.

HUMAN CENTRIC CPS FRAMEWORK

Fig. 1. shows our human-centered CPS system[6] architecture consisting of six interconnected levels. Below is a brief description of each tier:

Sensing Tier-This tier consists of sensors for flow, sound, pH and emissions or contamination. These sensors may also be divided into static sensors, sensors that track ambient temperatures, as well as proper working valves and pumps, and dynamic sensors that track the in-pipe system continuously, as well as geographical position of the nodes. The sensor information is partially cleaned at node level, and then transmitted to the server where the data is processed in full. Processing Tier – The processing tier conducts thorough data cleaning in real time after obtaining the partially cleaned data from the sensors, and can also archive the data for historical referencing.

Modeling Tier – The data processed is then fed back to the modeling stage. This tier consists of Hidden Markov models for predictions of demand trends and for assessing distribution of pollution.

Decision Fusion Level – The outcomes from the spread models of demand and pollution are then fed to the fusion level of decision. Here the cyber decisions are taken in line with the standard artificial intelligence models and these decisions are learned by the cyber systems through the processes of learning and preparation for correct future decisions.

Human Tier – Cyber model decisions are not placed on the system immediately but further evaluation of the decision is made in this all important human tier where humans are involved in the process feedback. Together with the human agents responsible for manual device management, this human input makes the human structure essential. If viewed by humans as a false alarm, humans can overrule the cyber decisions. Human decision result is controlled by the system and used for training the system in the learning models.

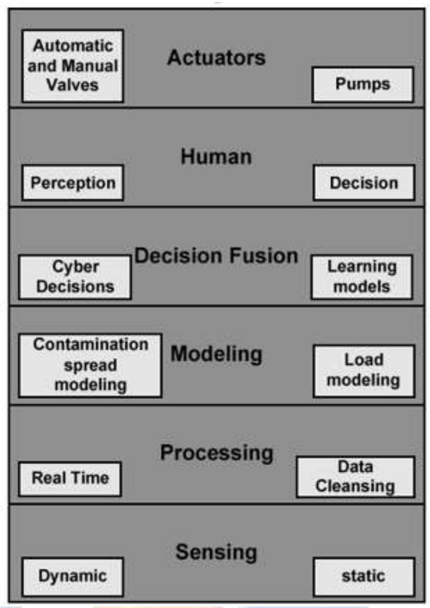

Fig. 1: Cyber Physical Pipe Sensing System

Actuator category – The actuators may be either manual or automatic valves and pumps, which can be used to avoid, open, raise pressure and isolate a section of pipes in the event of leakage, pipe bursts or to avoid contamination spread. The final decisions to carry out the specified tasks are sent to human operators and automated systems.

The sensing tier then controls this device again to assess the outcome of a particular decision. The whole cycle is displayed in a flowchart form in Fig.2. Let's consider a hypothetical case, for example, where sensors picked up high levels of pollution from a certain poisonous item at a given location. This sensed information is then processed and cleaned in real time and given to the modeling tier which has spread models of pollution to isolate the portion of the pipe and prevent the water from being dispersed from this area. The models bring the data into various scenarios and submit outcomes to the fusion of decisions where the HMM models take a suitable decision. Such decisions are sent to decision-makers who then decide / judge the decision according to their interpretation, and they may bypass the cyber decision and send their decision in the form of alert messages to the physical actuators. Using a learning model, cyber machine must learn from the result of human decision. Some incidents that cause leakage and pipe bursts can be managed very effectively via the physical structure of the human centric cyber. In the event of the aforementioned incidents the program will assess the best possible water routes. The same program can also advise authorities that they will send maintainers and engineers to the areas concerned for monitoring and control. In short, the decisions. Taken shall be forwarded to the authorities warning customers of a possible threat and administrators to monitor any unexpected occurrence.

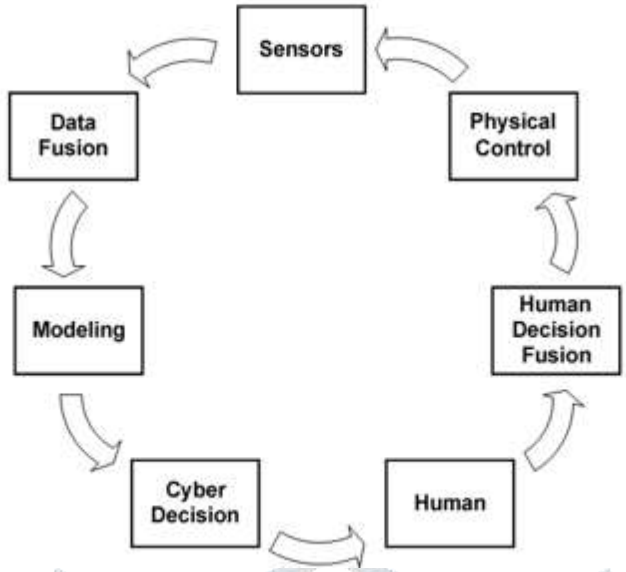

Figure 2: Flow Diagram of the Cyber Physical Pipe Sense System

PROPOSED SYSTEM

Because of the distributed nature of our system agent-based modeling is selected. In addition, some of the simulation frameworks suitable for our system has been tested, and consider EPANET 2.0 for physical layer simulation, which is open-source software designed by the Environment Protection Agency (EPA) [7]because of its ability to cover a wide range of water distribution attributes. A practical model for CPS should consider the randomness of the system environment in which the sensors were deployed and the components of the system that are actually intelligent agents.

There are various methods available in multi-agent systems that can be used to explain how each agent makes decisions, such as genetic programming, enhanced learning, rules-based reasoning, game theory and neural network. However, Bayesian models using Hidden Markov Model (HMM) [8]which is one of the best tools is used to recognize and predict demand patterns and contamination spread within the data collected.

HMM is a statistical model in which the system being modelled is assumed to be a non-observed Markov process. An HMM is a stochastic process created by interrelated underlying probabilistic mechanisms called the Markov Chain, with a finite number of states and a collection of random functions associated with states where the states are not directly visible, only state-dependent output is visible. Each state is linked to a distribution of probabilities over the possible output symbols. HMM[9] generates the sequence of symbols which provides information about the state sequence. One of the models for resolving and predicting the trends of demand and pollution spread to some documented events.

We consider a system that can be defined as one of a set of 3 distinct regularly spaced time states at any time;

State 1: Future Demand (FD)

State 2: Water Quality (WQ).

State 3: Contamination Spread (CS).

These states are the result of one or more of the three production choices, such as data showing changes made in the water delivery system, 'Expand Water Delivery System (EWDS),' improvements made in the treatment system, 'Improve Water Treatment (IWT)' and the number of times a particular water distribution system component is isolated in a given month, 'Isolate Contaminations (IC).'

The system undergoes a change of state (maybe back to the same state) according to a collection of state-related probabilities and denote the instants of time associated with change of state as t = 1, 2 and 3. The above stochastic process may be called an observable Markov model, since the output of the process is the set of states at each moment of time, where each state corresponds to a physical (observable) event and made some informed guesses for the probabilities of beginning in eq. (1) However, since it do not have adequate data, this will serve to evaluate our model well. Following validation of our model with this dummy data, which can easily provide the real data for analysis.

Start Probabilities:

{FD = 0.5, WQ = 0.3, CS = 0.2} (1)

Probabilities of transfer reflect the shift in the properties of the water distribution in the Markov Chain. After several test runs in the real scenario, those probabilities will be determined.

This paper have arranged the emission matrix on the following assumptions; if FD increases then there is a 40 per cent chance that the water distribution system will need to be expanded. If WQ rises then it is needed to strengthen the water treatment system by a 30 per cent chance. If CS increases then there is a 50 percent chance that the contamination will need to be isolated. Author use this HMM to ask ourselves about the possibility of extending our current water delivery network in the future, enhancing water quality through treatment and the need for potential isolation of pollution per affected region.

We can determine the likelihood of the following properties for an observation series in equation (2) over a span of 6 months.

O = {IWT, EWDS, EWDS, IC, IWT, EWDS} (2)

Author used Viterbi forward algorithm which was commonly used in HMMs to obtain the likelihood of the observation sequence. To get a meaningful sense, the above observation sequence can optimize, in other words it is found that a state sequence which would most likely have generated this output sequence. This Viterbi forward algorithm shows the likelihood of eq.(4) being 0.0019 and with likelihood 1.59exp-5 the optimal direction of states for this observation sequence is {FD, WQ, WQ, CS, FD, FD, FD.}. The Viterbi path contains seven states, as the sixth state and a transition to the seventh state created the seventh state. This model may also be change the parameters of the model such as transformation, emission and initial probability to increase the likelihood of an observable sequence. This model is just a simple example; after some modifications, more complex situations can also be effectively managed through the same model. Due to the limited space in this paper, models of learning and decision for the proposed framework were not debated.

CONCLUSION

Pipe Net offers a number of noteworthy properties, including: automated detection of leaks and bursts in water transmission pipelines; almost real-time operation with few false alarms; applicability to a range of pipe materials; inexpensive production, installation and maintenance; high-frequency data collection; the ability to distinguish between sensor and system faults and flexible, reusable data collection; The Pipe Net will provide a much-needed increase in hydraulic, acoustic and water quality data in spatial and temporal resolution that will improve the ability to understand and monitor large-scale water supply and sewer systems. It is of great importance to sense various aspects of the water delivery system and share this knowledge in order to monitor, conserve and enhance the water quality. This paper introduces a CPS architecture for Pipe Sense which is an in-pipe water monitoring device based on RFID WSNs near field. The design of the CPS system and a proposed model for demand pattern and distribution of pollution for water were identified. Furthermore, it proposed directions for further research and development and their effects.

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