GasNet^{TM}: Sensing and communication network system for low- and high-pressure distribution gas mains

Hagen Schempf
hagen@automatika.com

Noellette Conway
noellette@automatika.com

Automatika, Inc.
137 Delta Drive
Pittsburgh, PA 15238

I. Abstract

The use of distributed sensor gathering in real time in distribution mains is feasible through the use of the GasNet^{TM} system. A project funded jointly by the NorthEast Gas Association (NGA) and the National Energy Technology Laboratory (NETL) within DoE, developed and field-tested the upgraded field prototype capable of measuring key variables in distribution mains and collect such data in real time over a networked set of nodes from a single location. The data revealed the dynamic behavior of the network as a function of location and time. Such data is expected to be valuable in future network modelling, load-adjustment, predictive maintenance and possibly infrastructure security applications. This paper presents the overall system development program and Phase II results, as well as the future directions for this joint effort.

II. Introduction

Utilities need information about the in-situ process variables in their distributed network with sufficient resolution to enable them to better manage their infrastructure. When a utility lays out a new network, a computer-model of the network is utilized[1] to predict pressures and flows in the system. This allows the utility to size compressors and/or storage facilities, to provide for the necessary flow and pressures. Once installed however, the only real-time monitoring (and control) that occurs in the field is typically at the actual pumping/storage/ regulating facilities.

This severely hampers gas distribution infrastructure management efforts. Pressure and flow-variables are used to adjust supply and demand from the field - a basic reactive system approach. Additionally, data from every individual gas-meter is collected over time and used for billing in an offline process. Comparison of metered-and-billed volumes and those measured at the supply centers as having been pumped, can give some indication of the state of the network. Electric power utilities already use a phone-connection with individual customer-meters at each dwelling, allowing for regular consumption monitoring (for billing) with minimal manual effort. However, this is not considered a real-time network-wide measure. Gas utilities are beginning to realize the importance of automated pipeline management systems, but they are far from widely applying these technologies.

1. so-called ***Stoner*** Model

III. Background

Current state of the art in sensing and communications has clearly advanced substantially, as evidenced by the prominence of SCADA systems in the critical node-point locations of the national gas grid: production, transmission, including all the way to pumping and regulator stations. Included in such advances is the ‘Smart’ Regulator (see Figure 1).

Figure 1 : Smart Regulator - Fisher & Yankee Gas

Communications advances have also worked their way into the gas monitoring and billing sides of the business, as evidenced by the availability of remote monitoring and wireless (pager, satellite, cellular, etc.) data-transfer and -billing information forwarding (see Figure 2).

Figure 2 : AMT Systems

Submitted as a Full Paper to: GTI Natural Gas Technology III Conference, Jan.30 - Feb.2, 2005, Orlando, FL

Process sensors monitoring flow, pressure and gas-quality all exist but are mainly targeted at the transmission- or gate-house side of the business and represent accurate and costly assets for a utility (see Figure 3).

Figure 3 : Industrial-grade sensor systems for gas mains

IV. Project Overview

Gas utilities have little, to no, information about the in situ process variables in their gas distribution networks. This severely hampers gas distribution infrastructure management efforts. Automatika Inc., in partnership with the NorthEast Gas Association (NGA - formerly known as NYGAS - New York Gas Group) and its associated utilities, under funding from the Department of Energy (DoE) National Energy Technology Laboratory (NETL) Strategic Center for Natural Gas (SCNG), developed the proof-of-feasibility prototype for ***GASNET***^{TM}, a stand-alone, distribution pipeline sensor network system for real-time monitoring of live distribution gasmains.

The objectives of the ***GASNET***^{TM} program are to provide gas distribution utilities with the information they need to 1) access, maintain, monitor, and repair gas distribution systems, 2) track distribution system related activities - particularly third party activities which may pose safety concerns, and 3) model and design new networks. The ***GASNET***^{TM} system concept addresses 5 key needs of gas distribution network managers. The system can 1) provide alarms for certain types of potentially-damaging encroachment by third parties, 2) enable detection of substantial leaks, 3) provide cost effective monitors and sensors, 4) result in virtual models for gas system analysis, and 5) provide improved and cost effective data acquisition, system monitoring, and control capabilities.

V. System Overview

GASNET^{TM} is a wireless, self-powered network of keyhole-installed and keyhole-replaceable field-sensors capable of measuring, and communicating wirelessly through the pipe, key process variables such as pressure, flow, water-vapor content, temperature, vibration, etc. The data is sent in real time to a utility's central-control station. This process information will allow utilities to monitor the delivery process across their entire network from a single computer-console.

The concept of installed nodes and remote supervision is depicted in Figure 4, where artist renderings indicate where the nodes would be installed and how this data could be relayed in real time back to a centralized monitoring console within a utilities' operating center.

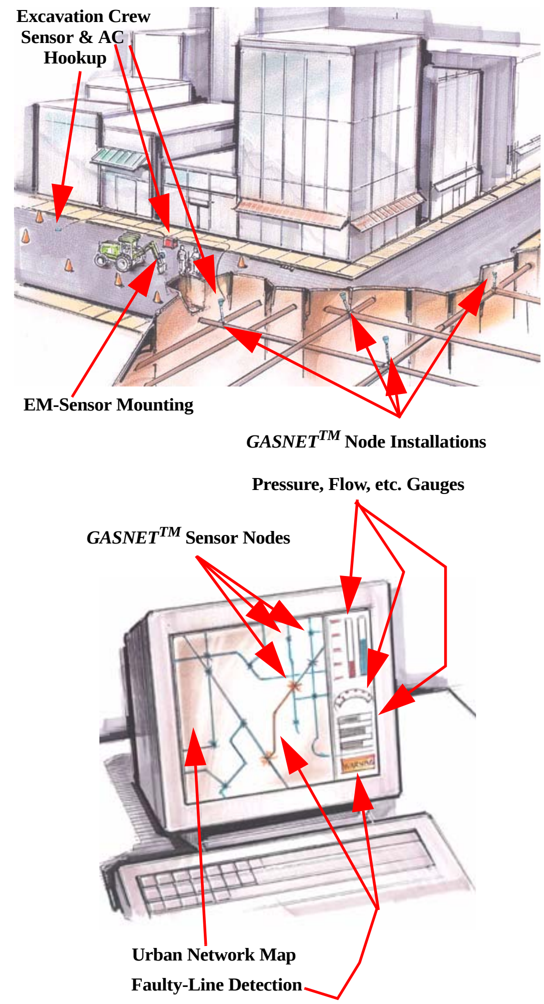

Figure 4 : Artist rendering of the GasNet^{TM} system setup

Note that Figure 4 indicates using the nodes not just for data-collection for network monitoring purposes, but also as a potential monitoring system for third-party access and accidental damage monitoring.

VI. Technical Overview

The ***GasNet***^{TM} system, consisting of the pipe-internal sensor-wand, safety-housing and power-supply, as well as the remote graphical user interface subsystems are described in more detail in this section. This section is laid out to address the overall system layout, and then delve into each subsystem in more detail.

The entire system design, as visualized through CAD renderings, was made up of the pipe-internal sensor wand, the external safety enclosure housing the electronics, the off-board power supply unit, and the remote user interface. A depiction of this system architecture is shown in Figure 5 (excluding the GUI):

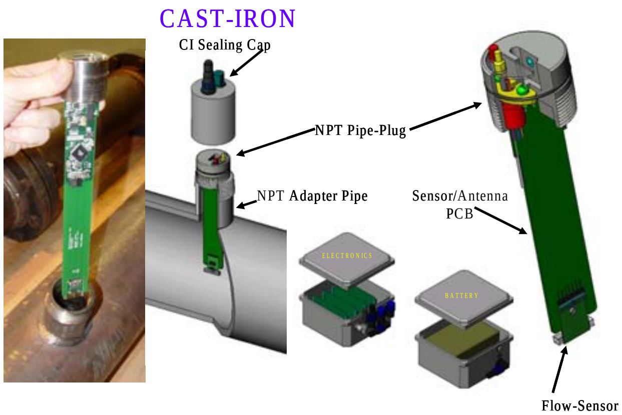

Figure 5 : GasNet™ Pre-Prototype System CAD-View

A final assembly view of the entire system is shown in Figure 6:

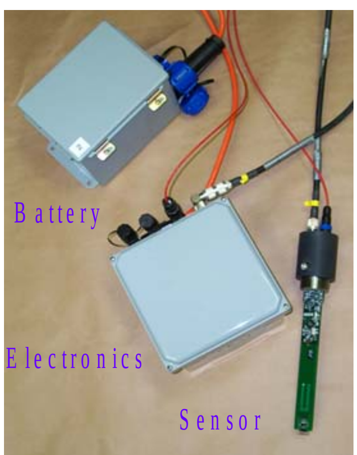

Figure 6 : GasNet™ system pre-prototype assembly view

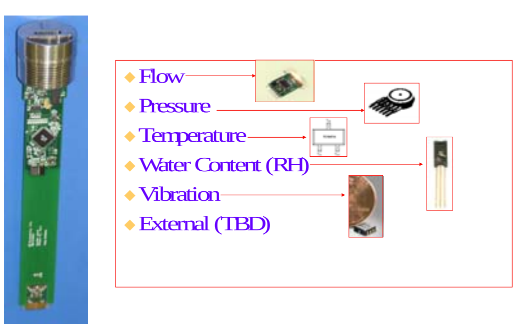

Figure 7 : Sensor-wand design and sensor options

The sensor-wand itself consisted of a single PCB, which was potted in a machined NPT fitting. The different elements and main sensor elements were laid out on the sensor-wand in the proper locations. A diagrammatic overview of the wand and its associated sensors, can be see in Figure 7.

In order to accommodate several pipe-diameters, and to ensure that the gas-flow velocity sensor would reside at the centerline of the pipe, the board was designed with break-off notches so as to allow for proper alignment during potting operations into the stainless NPT-plug.

The electronics were based on a simple architecture, relying on a dedicated microprocessor to poll all the sensors on the wand, while interfacing to the wireless RF-electronics over a simple serial-cable with a pre-established protocol. The diagrammatic depiction of the simple architecture is shown in Figure 8:

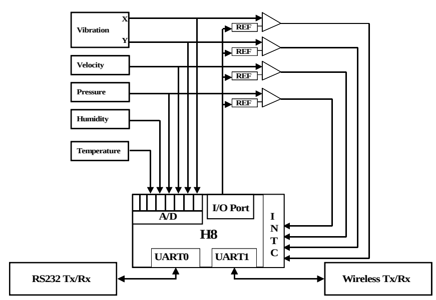

Figure 8 : Simplistic block-diagram of electronics architecture

The wand-PCB when fully populated, assembled, potted, and enclosed, is shown in Figure 9:

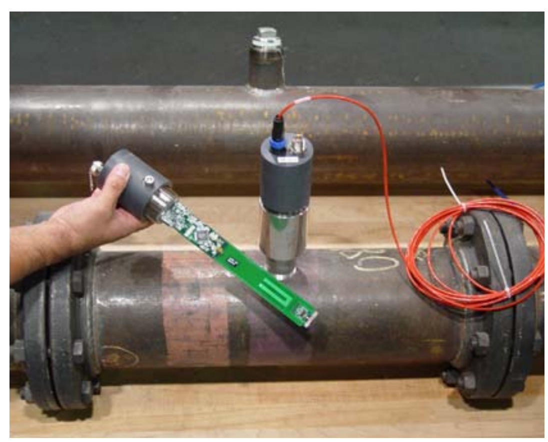

Figure 9 : Populated sensor-wand in test-pipe

The electronics enclosure that was developed to connect to the NPT-plug housed all the main electronics for operational safety. A picture of the sealed housings for both power and electronics, sensor-node, and associated cabling, is shown in Figure 10:

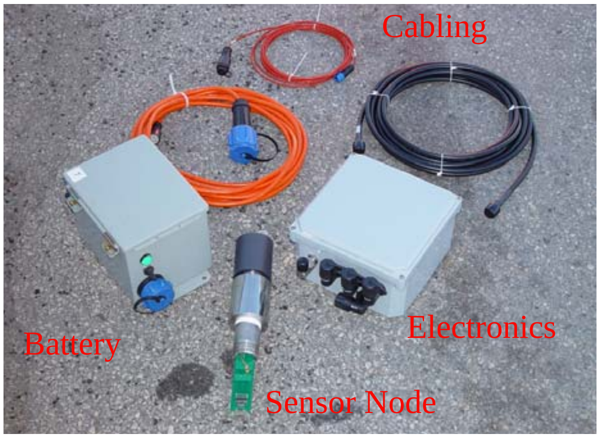

Figure 10 : Safety Enclosure Unit

The power subsystem consisted simply of an enclosure with OEM NiCad battery cells wired in parallel to allow for week long field-trials. The unit had a simple power-on indicator and a sealed on/off switch. The unit was connectorized using a screw-on sealed connector pigtail with a 30-foot long power-cord to allow it to be remoted from the excavated pipe and hole during field-trials. An image of the battery enclosure is shown in Figure 11:

Figure 11 : Battery power enclosure with cabling

The sensor-node NPT-plug was also designed to allow it to be used for no-blow installation using Mueller tools, thereby being able to be installed into cast-iron and high-pressure (< 124 psig) steel mains. An image of the required installation hardware is shown in Figure 12:

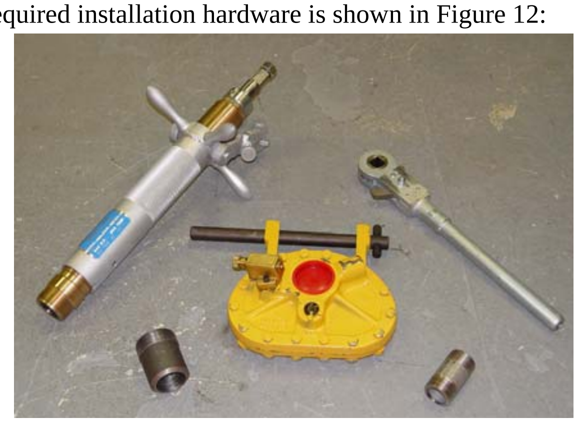

Figure 12 : No-blow Mueller installation hardware

The GUI (Graphical User Interface) was developed based on the premise of displaying a single unit's data in a large graphical form-factor, while having the data for others readily available and being able to switch which wand was being displayed at will. The implementation was carried out under ***LabView***^{R}, in order to maximize flexibility during testing, even if sacrificing system performance and throughput. A screen-capture of the final GUI layout is shown in Figure 13.

Figure 13 : Test GUI screen-capture layout

The individual units can be deployed in a network mode, where each unit is a sensor-gathering node (also termed a slave), capable of transmitting its data through the pipe-cavity in wireless format, to another node to either act as the central data-collector (also termed 'master'), or to a repeater, that simply relays the data to another repeater or master - such a network topology is shown in Figure 14:

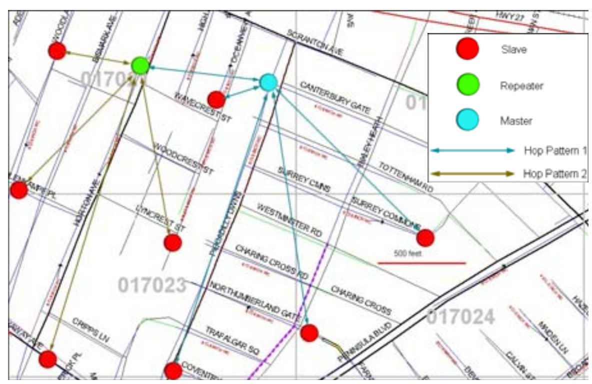

Figure 14 : Wireless network topology example

On-board configuration switches define each unit's ID number and master-slave designation. In this Phase II implementation, the system was designed for one master in the network and as many repeaters or slaves as needed. Firmware programmed into the micro controllers differed slightly depending on the master/repeater or /slave designation of the node. Master nodes were set up to copy messages from the local serial port to wireless and vice versa, thereby allowing a data logging hook-up while also serving as a relay node. In this manner, the master relays all messages between a user interface and the rest of the nodes in the system. In addition, the electronics had a data logger that logged all data to an SD memory card for post-processing.

The software resides on multiple 8-bit micro controllers which run custom firmware to interface to pressure, velocity, relative humidity, temperature, 2-D accelerometer, two serial communication devices and digital potentiometers. The digital potentiometers are set up to provide voltage thresholds for providing ‘alarms’. One serial port (local) is connected to an RS-232 transceiver, while the second port (wireless) is connected to a wireless transceiver unit running its own proprietary software.

The 8-bit firmware implements three different work modes: one special work mode state, and two configuration modes. Different work modes are defined to allow different levels of power conservation and interactivity of the system. The flow chart in Figure 15 captures the operation of the firmware in different modes in a single image (configuration modes allow user to configure and run diagnostics on the node).

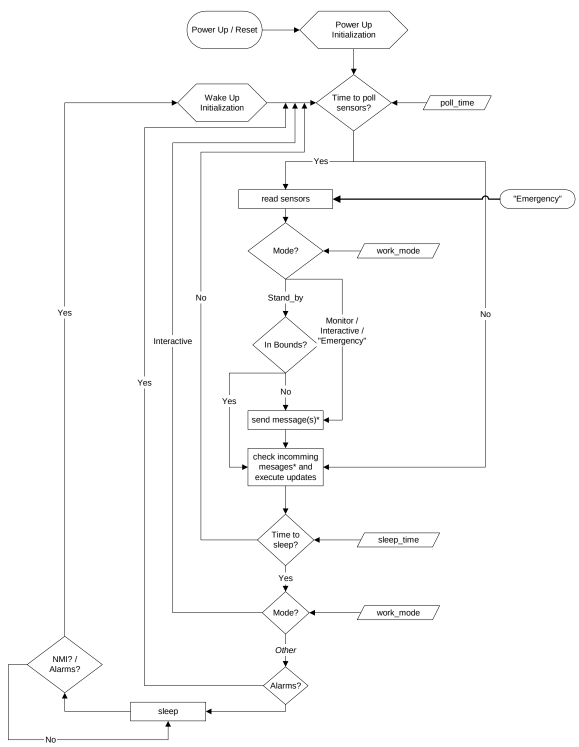

Figure 15 : Software mode flow chart diagram

A more detailed description of the modes can best be detailed as follows:

Interactive mode keeps the system continuously running without ever going into a hardware power saving sleep state. This mode is useful for continuous monitoring and reporting of the gas main conditions.

Monitor mode is useful for periodic checking of the gas main conditions. In this mode, after reporting the data, the node goes into a sleep state for a user-defined period of time.

Standby mode uses user-defined upper and lower bounds for each sensor. In this mode, the node will behave just like it does in the Monitor mode except the data is only reported if any of the sensors’ readings falls out-of-bounds.

The node enters an Emergency state while in any of the work modes, if one of the hardware alarms is triggered. Emergency state wakes-up and prevents the node from going into sleep mode until the user deals with the alarm conditions. When the alarm disappears, the node returns to the previous work mode.

Transparent mode allows the user to configure wireless modem settings using a local serial port. Once the user exits this mode the system returns to the previous work mode.

Self-test mode performs a diagnostic on internal sensors and prints results to a local serial port. Once the diagnostic is finished, the system returns to the previous work mode.

VII. Experimental Results

The chosen field-trial location was in Valley Stream, NY, with the support of KeySpan Energy, Inc., where 4 nodes were installed in a master/repeater/slave setup along an 8-in CI main - see Figure 16:

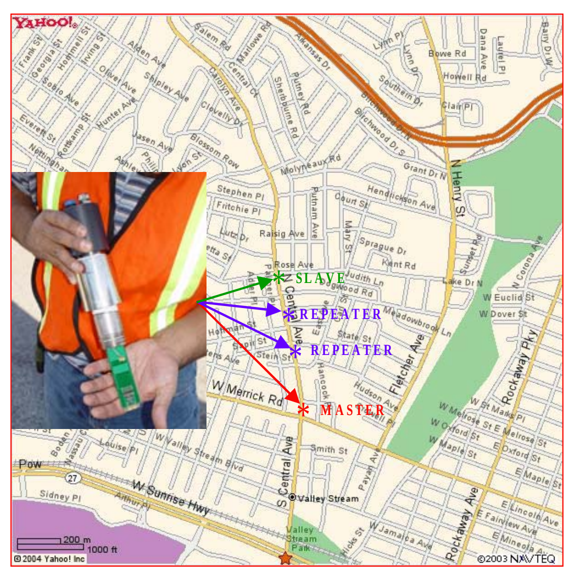

Figure 16 : Valley Stream Test Site installation

The setup of the system involved the installation of multiple such units in a cast iron main, and have them collect data and communicate it through the pipe wirelessly to a single node that would be used to extract and log the data. A prototype unit of the field-installed prototype, is shown in Figure 17.

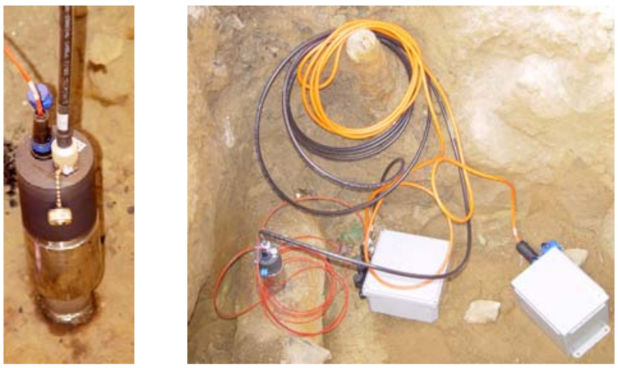

Figure 17 : Prototype unit installed in a live CI main

Experimental field-testing showed gas flow rates to exhibit highly dynamic and oscillatory behavior varying widely across even a $^{1}/_{2}$ mile stretch, in terms of amplitude (flow-rate) and -direction and time-of-day (see Figure 18).

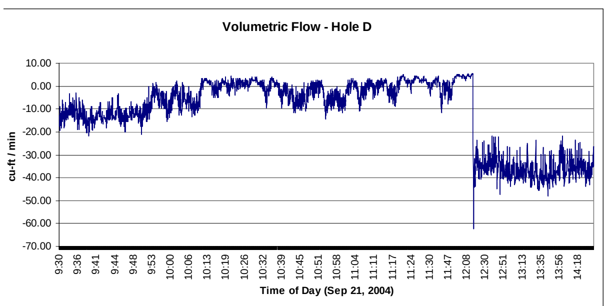

Figure 18 : Typical Flow Data over 5+ hours

Limited pressure measurements showed that pressures were in the statically-predicted range, however dynamic behavior (if any) was not detectable. Gas temperature and water content were found to be extremely steady, with increasing temperatures of the gas flow over time due to heat-up of the sensor-wand unit since we were performing an open-hole field-trial (due to IR-absorption from sun-rays). Water content was extremely low and measured at less than 0.1% by volume. Mechanical pipe-wall vibration measurements again proved to be capable of picking up heavy traffic activity (trucks mainly) within the vicinity of an instrumented pipe-section due to the segmented and isolating nature of the cast-iron bell-and-spigot design.

VIII. Summary and Conclusions

The ***GASNET***^{TM} system was shown to be a feasible technology in terms of its capability to collect, transmit and log data over a distributed network of sensors. Challenges remain in the area of mapping wireless in-pipe performance, the accuracy and reliability of OEM sensor hardware and the ability to present and utilize the real-time data in a manner not only meaningful, but also of impact to the bottomline of the O&M departments within distribution utility companies. The results to date continue to indicate that a solution in the near-term is reachable and indicate that this technology be pursued further and packaged for use by urban utilities.

IX. Future Activities

AI is currently engaged in Phase III activities, in which the effort is focussed on (i) multi-unit build for field-installation, (ii) modular wand re-design to allow for use of TDW installation equipment, (iii) sensor upgrade/ replacement and calibration for cast-iron & steel, (iv) designing the data-retrieval to allow for wireless PDA downloads, and (v) three (3) field-trial installations of up to 30 units at the end of the phase, requiring longer-term below-ground installations with surface access.

X. Acknowledgements

AI wishes to acknowledge the funding-support of the U.S. Department of Energy Office of Fossil Energy National Energy Technology Laboratory through co-funding this work under contract #DEFC26-02NT41320[2]. We wish to also thank NGA for co-funding this effort to date under a separate fund-matching contract. Special thanks go to Keyspan Energy, Inc., and in particular Mr. Joe Vitelli and Mr. Daniel Deletto for facilitating, managing and supervising the week-long field-trial of the ***GasNet***^{TM} system in Valley Stream, NY in mid-September 2004.

The ***GASNET***^{TM} technology currently has several US and international patents pending.

XI. References

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2. Any opinions, findings, or conclusions, or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the DOE.