

# GasNet<sup>TM</sup>: In-situ real-time data-gathering and communications network for distribution gas pipe networks

Noellette Conway  
noellette@automatika.com

Hagen Schempf  
hagen@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<sup>TM</sup> 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 first functional 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 its results to date, 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<sup>1</sup> 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.

## 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

---

1. so-called *Stoner* Model

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<sup>TM</sup>*, a stand-alone, distribution pipeline sensor network system for real-time monitoring of live distribution gas mains.

The objectives of the *GASNET<sup>TM</sup>* 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<sup>TM</sup>* 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<sup>TM</sup>* 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.

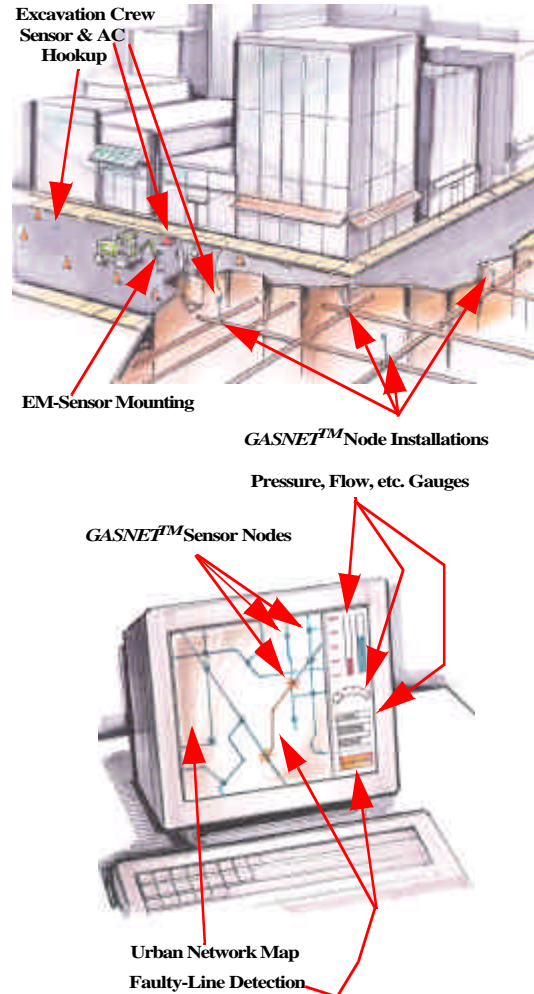


Figure 4 : Artist rendering of the GasNet<sup>TM</sup> system setup

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<sup>TM</sup>* 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:

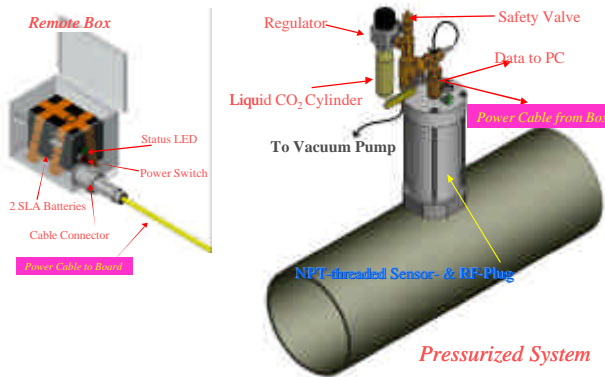


Figure 5 : GasNet™ Pre-Prototype System CAD-View

A final assembly view with shipping protector is shown in Figure 6:



Figure 6 : GasNet™ system pre-prototype assembly view

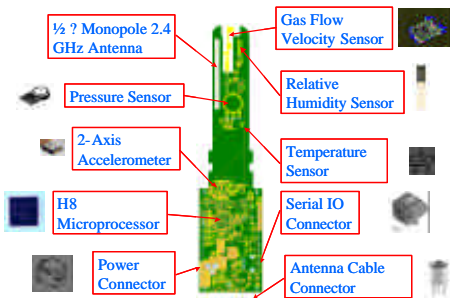


Figure 7 : Sensor-wand design and sensor layout

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 seen 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:

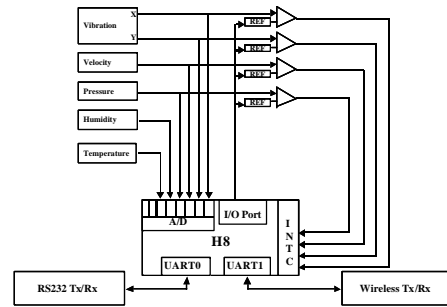


Figure 8 : Simplistic block-diagram of electronics architecture

The wand-PCB when fully populated, assembled and potted, is shown in Figure 9 and Figure 10:

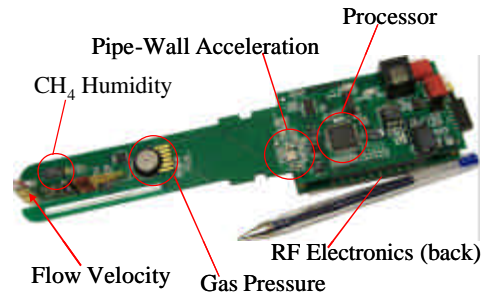


Figure 9 : Populated sensor-wand PCB



Figure 10 : Finished NPT-fitting Sensor wand

The safety enclosure that was developed to connect to the

NPT-plug was not only for protective use for the PCB, but also for operational safety. The procedure that was required by the utilities to be followed for installation and operation, necessitated that all non-certified electronics be purged and pressurized with a non-oxygenated gas. The approach we employed utilized a vacuum-pump that would evacuate the sealed electronics enclosure down to 1/10 of an atmosphere, after which a pressurized CO<sub>2</sub> cartridge would deliver inert gas into the enclosure through a regulator set to several psig above pipe-internal pressure; this state was preserved and monitored while the unit was powered up from the remote battery unit. A picture of the sealed housing, endcap, NPT-plug and associated safing gas-assemblies is shown in Figure 11:



**Figure 11 : 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 removed from the excavated pipe and hole during field-trials. An image of the battery enclosure is shown in Figure 12:



**Figure 12 : Battery power enclosure with cabling**

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<sup>R</sup>**, 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 software resides on an H8 micro controller which runs 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 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 the Phase I implementation, the system was designed for only one master in the network and all node ID numbers had to be unique. Firmware programmed into the H8s differed

slightly depending on the master/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.

The H8 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).

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.

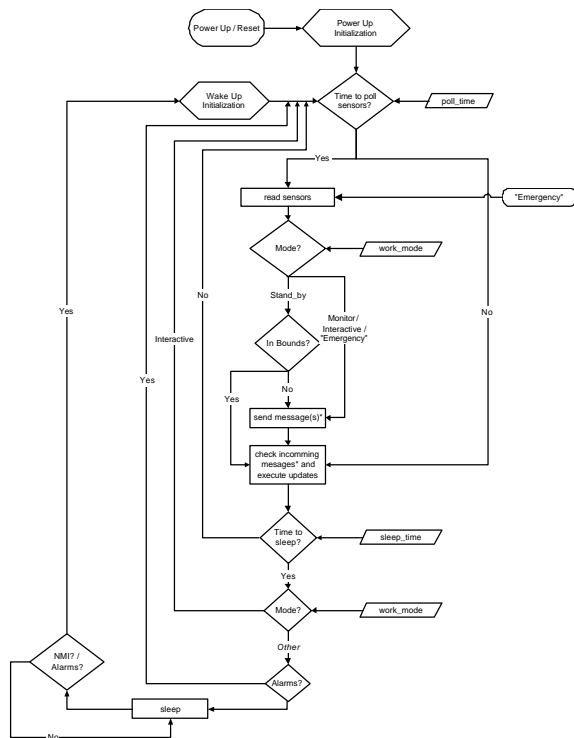


Figure 15 : Software mode flow chart diagram

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 setup of the system involved the installation of multiple such units in cast iron mains, 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 functional demonstrator (1 of 10) is shown in Figure 16.



Figure 16 : Functional pre-prototype unit installed in a live cast-iron gas 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 flow-direction as a function of time-of-day (see Figure 17).

Limited pressure measurements showed that pressures were in the statically-predicted range, however dynamic

behavior (if any) was not measurable due to premature sensor-failure. Gas temperature and water content were found to be extremely steady, with higher temperatures of the gas flow than ambient (independent of daytime temperature fluctuations). Water content was extremely low and measured at less than 1% by volume. Mechanical pipe-wall vibration measurements proved to only be possible within the vicinity of an instrumented pipe-section due to the segmented and isolating nature of the cast-iron bell-and-spigot design; measurements did however show that road-traffic could be ignored, while road-surface jack hammering was readily detected, as were impact-loads as small as a pipe-wall hammer-strike.

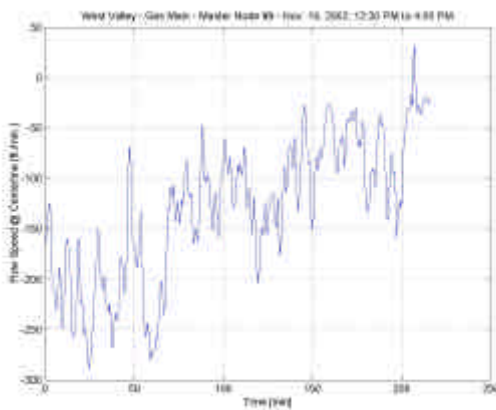


Figure 17 : Typical Flow Data over 4+ hours

## VIII. Summary and Conclusions

The *GASNET<sup>TM</sup>* system was shown to be a feasible concept in terms of its technology and its capability to collect, transmit and log data over a distributed network of sensors. Challenges remain in the area of optimizing wireless in-pipe performance, accuracy and reliability of low-cost 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 though clearly indicate that a solution in the near-term is reachable and indicate that this concept be pursued further and packaged for use by urban utilities.

## IX. Future Activities

AI is currently engaged in Phase II activities, in which the effort is focussed on (i) RF CI-/steel-pipe communication

characterization, (ii) modular wand re-design to allow for no-blow installation, (iii) sensor upgrade/replacement and calibration, and (iv) designing the same for a live above ground distribution steel-main medium-pressure ( $\leq 124$  psig; design rated for transmission-pressures though), and a live cast-iron main demonstration at the end of the phase. In addition, design details (i.e. on paper in terms of theoretical analysis and CAD design but not prototyped) are being developed for longer-term below-ground design 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<sup>2</sup>. 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. Daniel Deletto and Mr. Anthony Savino for facilitating, managing and supervising the week-long field-trial of the *GasNet<sup>TM</sup>* system in West Valley, NY in late November 2002.

The *GASNET<sup>TM</sup>* technology currently has several US and international patents pending.

## XI. References

- [1] Yoder, J., "Raising the Bar for Primary Elements", Control Engineering Magazine, October 2000.
- [2] Spitzer, W.D., "Practical Guides for Measurement and Control", Instrument Society of America, 1991.
- [3] McBride, A.E., "Going with the Future of Flow", Control Engineering Online, November 2000.
- [4] Schempf, H., Conway, N., "GasNet: Phase I Topical Report", DoE Internal Report Submission, April 2003.

---

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.