Natural Gas Pipeline Sensors

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**Project objective:**

- design, fabrication, lab testing, and field testing of next generation low-cost sensors and methods for use in natural gas pipelines.

Per the 2005 Integrated Energy Policy Report, this project will assist in expanding the analytical ability to determine the adequacy of the State’s natural gas infrastructure and likelihood of potentially destructive peak demand spikes, and also ensure that the State’s natural gas infrastructure can both convey and store supplies.
Laser Ultrasonic Testing and Flow

Low-cost MEMS Sensors

Low-power Wireless Mesh Network
# Microfabricated (MEMS) Nat. Gas Sensors

## Objectives

- Develop and fabricate low-cost/low-power pressure and flow sensors which can be used for ubiquitous monitoring of natural gas pipelines to increase their safety and reliability.
- Extend the fabrication process to enable wafer-level assembly of complete system, enabling low-cost deployable sensing solution.

## Accomplishments

- Fabricated first pass MEMS pressure sensor design using MEMS foundry service.
- Designed and fabricated masks for in-house pressure sensor fabrication.
- Modeling of non-thermopile flow sensor designs ongoing.

## Expected Results

- Design and fabrication of MEMS pressure and non-thermopile flow sensors.
- Integration of the sensors with a low-power radio wireless mesh network.
- Pilot test the sensor concept in field in collaboration with the utilities.
Low-power Wireless Infrastructure

Objectives

- Create a reliable low-power wireless backbone for sensor data communication
  - Provide interface with existing communication backbone, such as AMI network
- Extend the mesh network to support wafer-level integration of a deployable sensing solution

Accomplishments

- Designed the wireless mesh network based on Dust® WirelessHart.
- Implemented a local network architecture based on legacy GINA design.

Expected Results

- Develop a reliable low-power wireless network to support communication with the distributed MEMS sensors.
- Integration of the sensors with a low-power radio wireless mesh network
- Pilot test the sensor concept in field in collaboration with the utilities
Ultrasonic Diagnostic and Test Devices for Natural Gas Pipelines

Customer Problems to be Solved

- Evaluate non-contacting laser-based ultrasonic tool for inspecting pipeline welds, locating cracks, detecting pipe offsets and measuring pipe wall thinning due to internal or external corrosion
- Engineer wirelessly enabled low-power scanning ultrasonic gas flow sensor for unobtrusive installation in legacy and new natural gas transmission pipelines

Innovation goals

Laser Ultrasonic Test System
- Non-contact laser ultrasonic tool for determining pipe integrity when used on utility’s “crawler"

Microfabricated Ultrasonic Gas Flow Sensor
- Novel low-power approach to wirelessly enabled non-intrusive gas flow sensing

Project Plan
- Continue interaction with laser ultrasonic test manufacturer and utility to evaluate compatibility with existing pipeline crawler
- Complete analysis of operation of ultrasonic flow sensor based on existing prototype microfabricated scanning ultrasonic arrays
- Test array flow sensor in our air-flow tube setup
- Design for realistic incorporation of flow sensor in operating gas transmission pipes
Sensing System Design

- **Baseline design**
  - Sensors deployed as retractable probes into the gas flow via the ¾ inch access port.

- **Sensor suite**
  - Pressure
  - Flow
  - Accelerometer (external)

- **Wireless infrastructure**
  - Dust Networks (~70 µW standby)

- **Power**
  - Battery/Solar (>10 year lifetime)
Advanced Sensing Concept

- Advanced design concept
  - Self-powered sensor modules, powered by the gas flow, that autonomously instrument section of the pipeline.
Online sensors that would be useful

- Pressure sensors (MEMS/low cost)
- Flow sensors (MEMS/low cost)
- Vibrations sensors (distributed/low cost)
- Moisture sensors (MEMS/low cost)
- Odorant level sensors (low cost)
- Methane detector (low cost)
- Laser Ultrasonic's (Weld/Corrosion detection)
- Ultrasonic flow sensors
Capacitive MEMS Pressure Sensors

250 µm
Capacitive MEMS Pressure Sensors

New pressure sensor design
Non-thermopile MEMS design

- Dynamic pressure sensing:
  - Paddle or whiskers

Figure 2. Sensor structure with SU-8 hair.

Krijnen et al., 2006
MEMS Sensors - Next Steps

- Fabricate 2\textsuperscript{nd} generation MEMS pressure sensors
  - Mount and test in laboratory setting
  - Integrate with the wireless mesh network

- Fabricate flow sensors
  - Mount and test in laboratory setting
  - Integrate with the wireless mesh network

- Perform a limited pilot deployment and testing of the sensor packages in collaboration with the utilities.
  - Limited accelerated life-time testing
  - System integration analysis
Laser Ultrasonic Inspection Tool
Testing Welds

No Gap

Gap

Gap is not between generation laser and detection laser, so is not surveyed.

Gap is between generation laser and detection laser, so is surveyed.
Laser Ultrasonic Inspection Tool
Weld Test Results

Not over gap (good weld)

Over gap (bad weld)

Generation laser
Detection laser

Detected Signal
Laser Ultrasonic Inspection Tool
Pipe Offset Test
Microfabricated Ultrasonic Gas-Flow Sensor

- Novel microfabricated ultrasonic array transducer recently announced at BSAC could be used to measure natural gas flow rate (Profs. Horsley, Boser, and students R. Przybyla et al.)
- By scanning angularly or propagating within side stub as shown at left could measure flow rate (angular scanning capability shown at right)
Looking Forward – Next Steps

1. Continue interaction with laser ultrasonic manufacturer and utility to evaluate compatibility with existing pipeline crawler

2. Complete analysis of ultrasonic flow sensor based on available prototype microfabricated scanning arrays

3. Test ultrasonic flow sensor in our lab air-flow tube setup

4. Design for incorporating ultrasonic flow sensor in operating gas pipe (test if possible)