SewerSnort: A Drifting Sensor for In-situ Sewer Gas Monitoring

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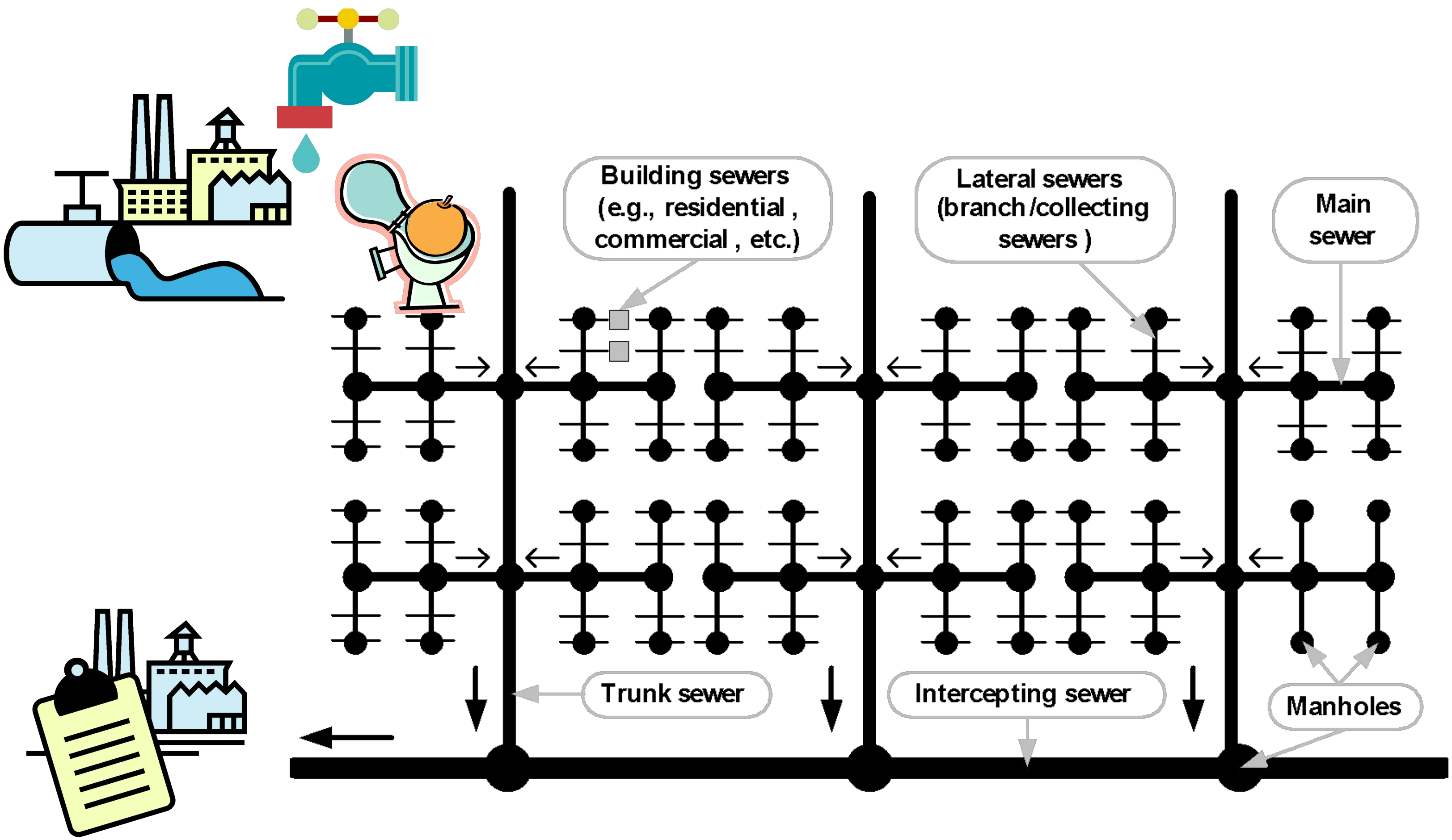
RAF® SYSTEMS

Wastewater Collection System (WCS)



Treatment plant

Aging WCS

- High maintenance and replacement cost: 1.6 trillion in 1996
- Soaring frequencies of system failure – over 1.3 trillion gallons of untreated wastewater was discharged to rivers or oceans in 2001
- Untreated sewer endangers public health and nature

manhole

sewer overflow

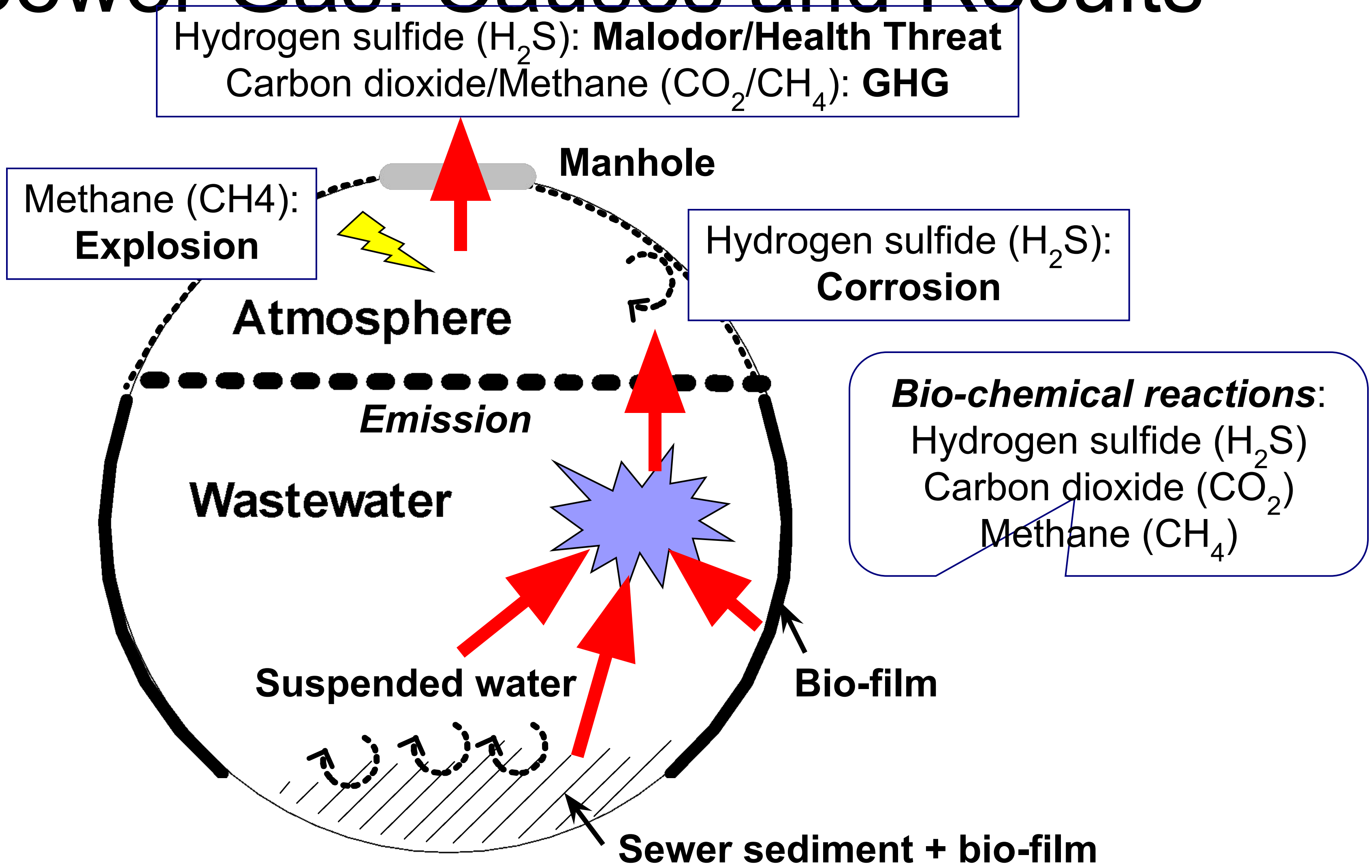
pollution

WCS Monitoring

- Hazardous and unfriendly environment makes WCS monitoring greatly **difficult and expensive**

- Current WCS monitoring practices:
  - Pipe damage detection (e.g., smoke/fluorescent dyes)
  - Flow monitoring at strategic locations (e.g., flow meter)
  - Sediment control (e.g., flushing/chemical treatments)
  - Toxic sewer gas detection (e.g., hydrogen sulfide, methane)
    - **Insight: sewer gas is a key indicator of sewer conditions**

Sewer Gas: Causes and Results

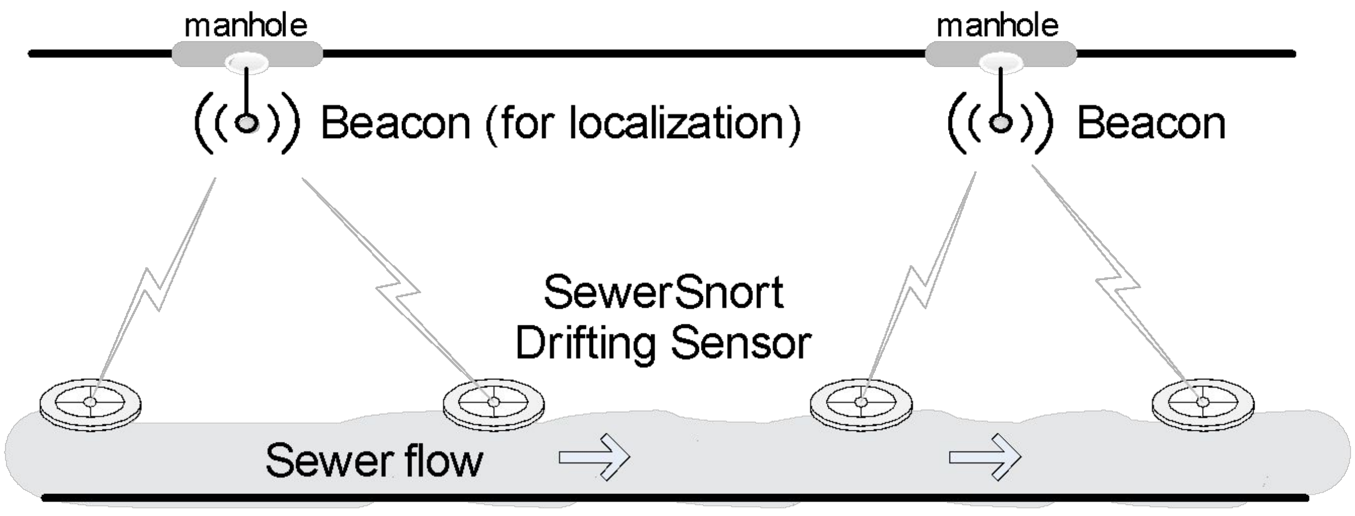


Motivation: In-situ Gas Monitoring

- Problems with current sewer gas monitoring practices
  - Only focuses on gas detection to avoid potential health threats
  - Limited sewer coverage
    - Portable gas detector carried by a sewer worker
    - Detector installation at strategic places (e.g., pumping station, treatment plant)
- Goal: develop an urban scale gas monitoring scheme
  - Scaleable (LA has over 12,000 Km sewer pipes)
  - Deployable with reasonable cost
  - Independent of pipe profile (e.g., circular, oval, or square type)

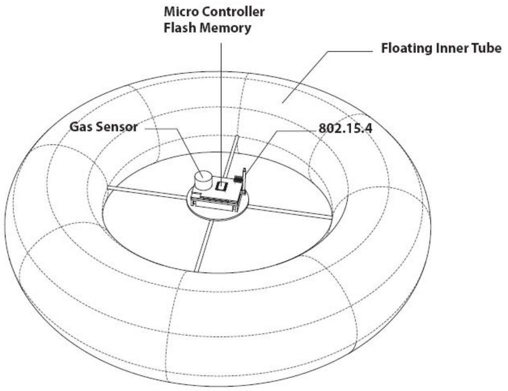
SewerSnort Drifting Sensor

- Gas monitoring using drifting sensors
  - Sensor dispensed upstream
  - Data collection downstream (treatment plant)

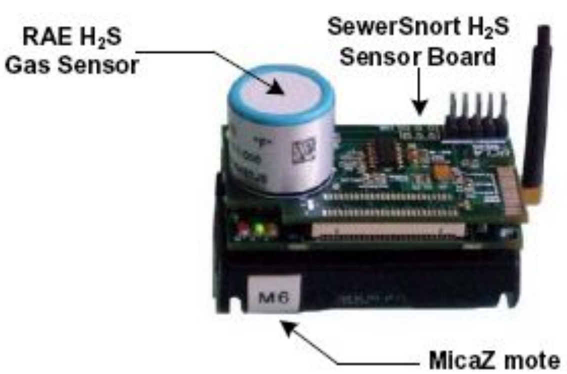


SewerSnort System

- Sensor node design
  - Hull design
  - Hydrogen sulfide (H_2S) gas sensing unit
- In-sewer localization
  - Sensor data geo-tagging



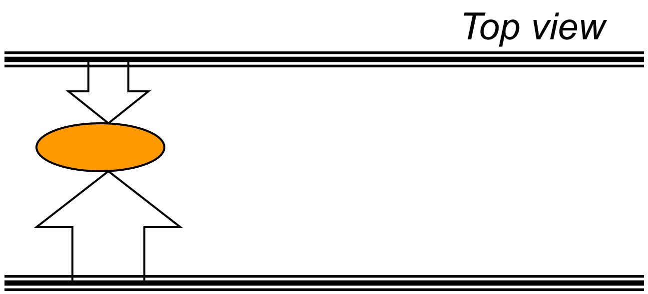
SewerSnort Hull



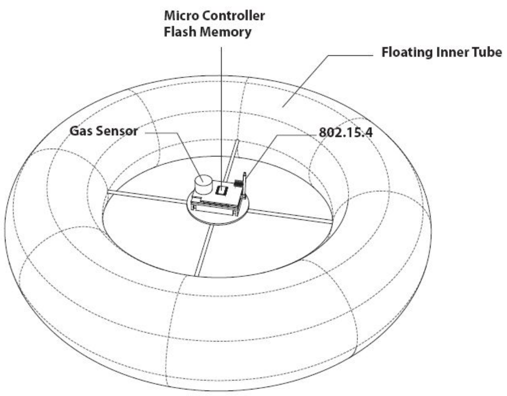
SewerSnort: RAE 032-0102-000 electrochemical sensor and custom Analog Front End (AFE)

Hull Design: Inner Tube Shape

- Drifter travels along a sewer without motion control
- Drifter suffers from bank suction:
  - Happens when a vessel is not on the center of a pipeline
  - Asymmetric flow speed causes pressure difference that pushes the vessel toward the side of the pipeline
- SewerSnort uses inner tube shape, rolling along the sewer pipe



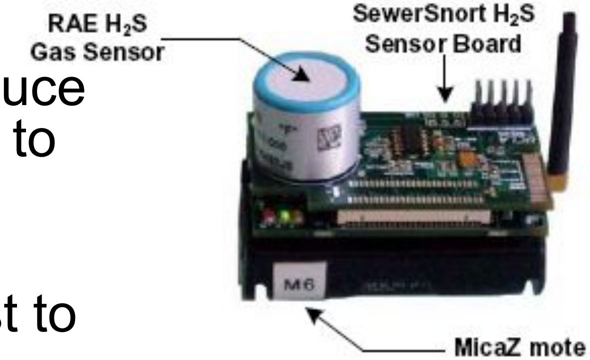
Pressure difference



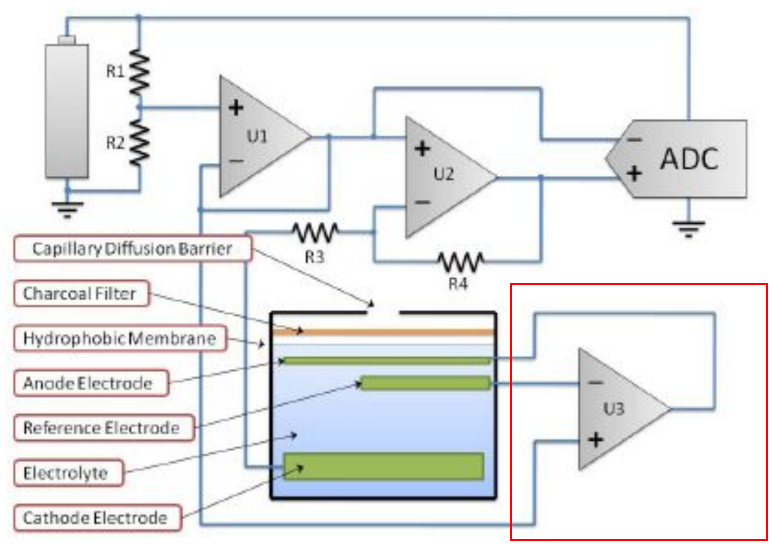
SewerSnort Hull

Gas Sensing Unit

- **Electrochemical sensors**: produce an electrical current proportional to gas concentration
- Stable/constant voltage is a must to maintain the calibration curve as SewerSnort is “battery-powered”
- **Ratiometric signal conditioning**
  - Generate reference voltage: fixed ratio of battery voltage
  - Use this reference potential to maintain the regulated output voltage



RAE H2s electrochemical sensor and custom Analog Front End (AFE)



Electrochemical sensor

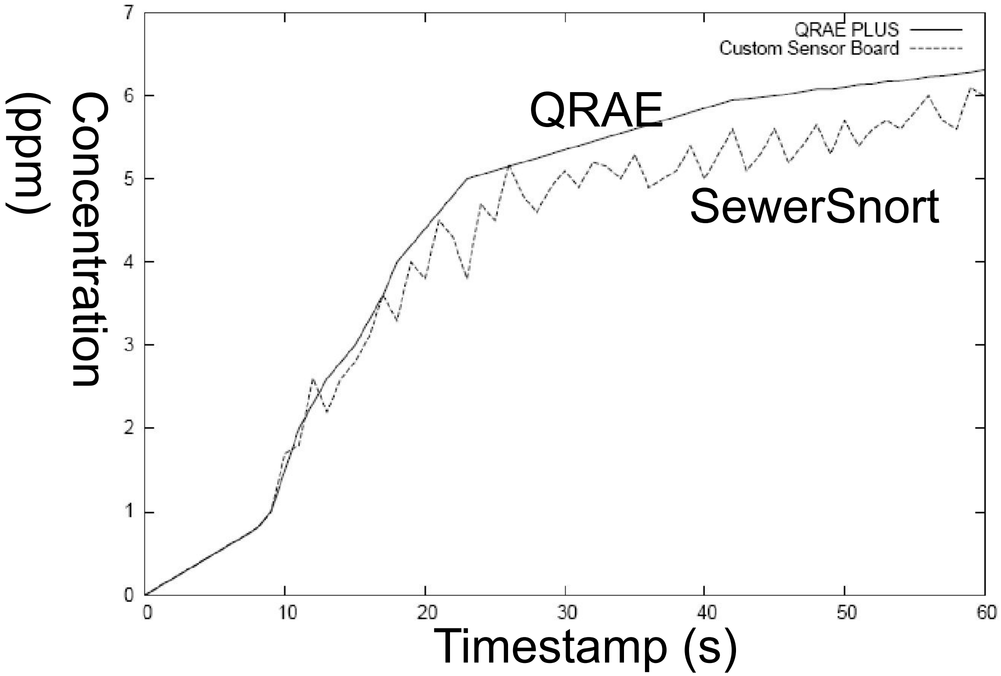
Ratiometric signal conditioning

In-sewer Localization

- RSSI-based localization
  - Periodic beacons from ZigBee radios on sewer manholes
  - Radio propagation model for concrete storm drain pipes: $RSSI(d) = P_{tx} - \alpha * d - A_{CL}$ (in dB)
    - α : conductivity of a sewer pipe
    - A_{CL}: antenna coupling loss
- SewerSnort: off-line location computation
  - While drifting, collect RSSI samples
  - At the end, perform de-noising (or smoothing) using Empirical Mode Decomposition (EMD), and use a calibrated propagation model for geo-tagging

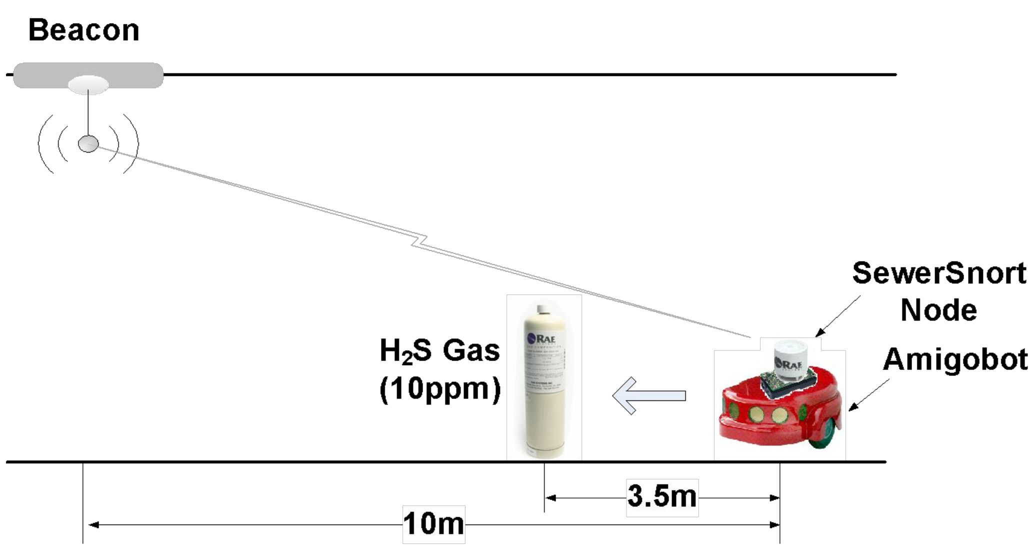
Lab Experiments:
SewerSnort H_2S Sensor Board

- H_2S lab measurement in an air tight container
- Comparison with commercial gas detector, QRAE Plus



Field Experiments:
SewerSnort Mobile Scenario

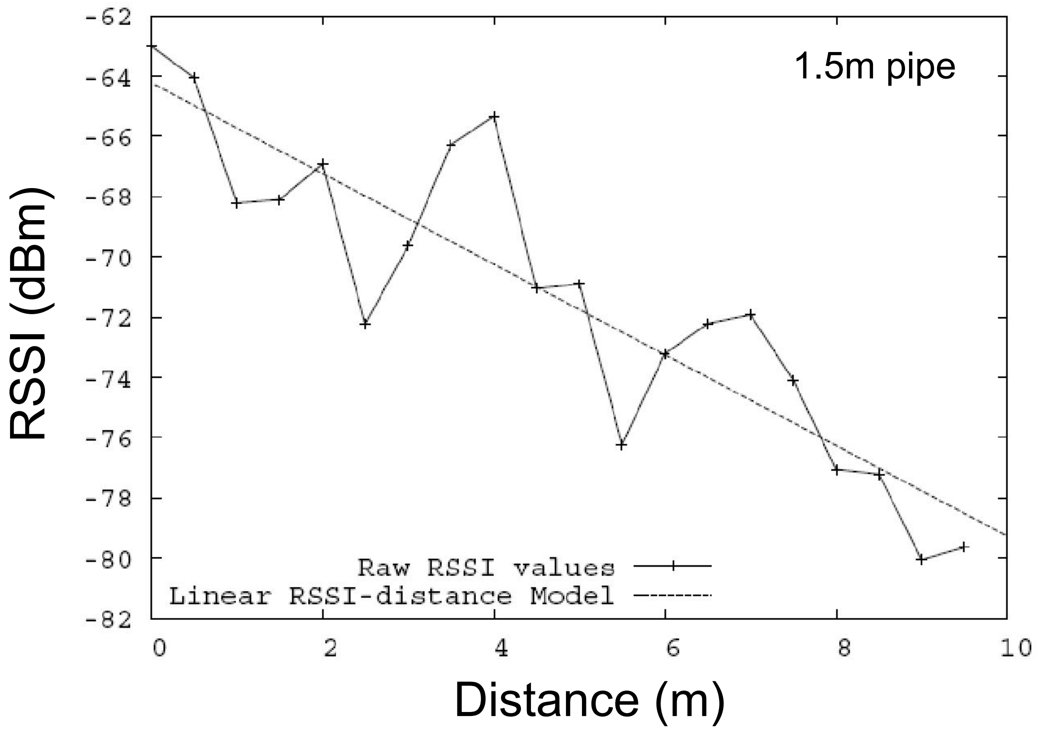
- Pipeline company yard in CA*
- SewerSnort on top of Amigobot, a mobile robot moving at the speed of 1m/s
- Concrete pipe with 1.5m/1.8m diameter



*Rialto Concrete Pipe Company

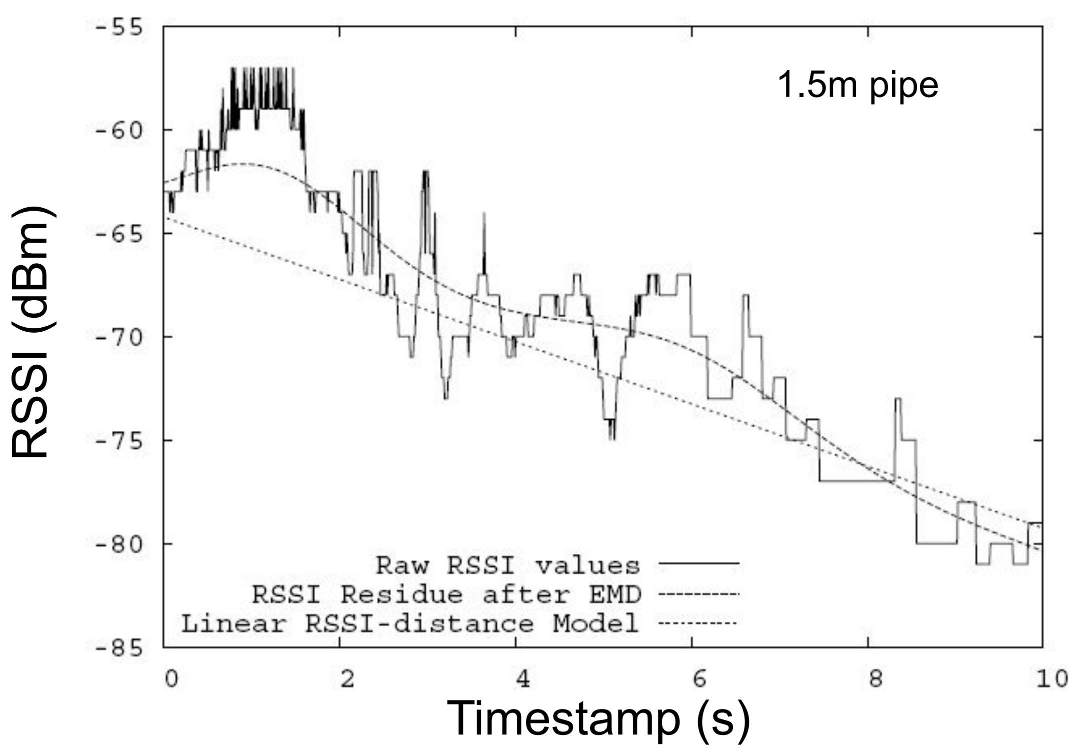
Field Experiments:
Radio Propagation Model Calibration

- Linear radio propagation model fitting using measured RSSI over distance



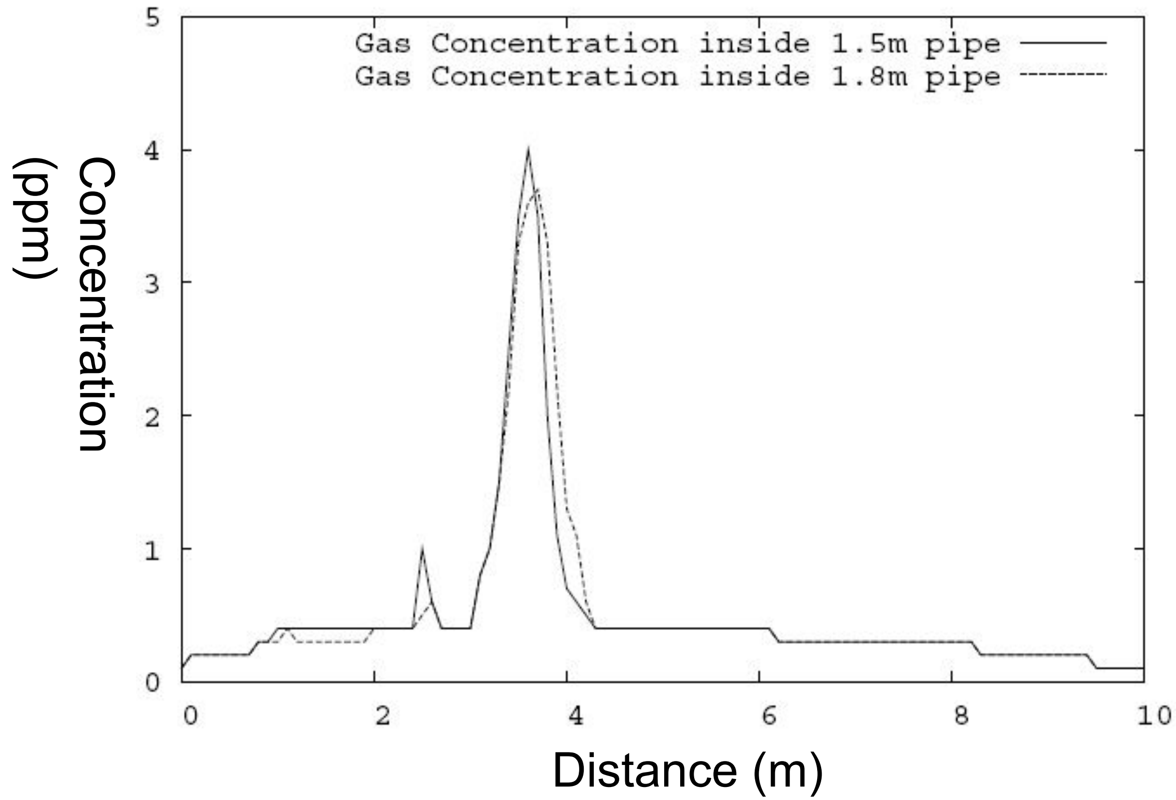
Field Experiments: *Off-line Location Computation*

- After smoothing, tune a constant speed drifting model
- SewerSnort localization (< 5% error)



Field Experiments:
Gas Concentration Measurement

- Measured H_2S gas concentration (ppm)



Conclusion and Future Work

- SewerSnort enables urban scale sewer gas monitoring
  - Inner-tube shape hull to handle bank suction
  - Ratiometric signal conditioning to generate regulated output voltage, thus maintaining the calibration curve
  - RSSI-based localization with error within 5% over hundred meters
- Demonstrated feasibility via dry-land based experiments

- Future work
  - SewerSnort testing in real sewers
  - Mobility model in sewer pipes
  - Sensor deployment strategies (coverage, connectivity, etc.)