Automated Monitoring of Pipeline Rights-of-Way

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Presentation Topics and Overview

- Damage Prevention – Drivers & Challenges
- Successes of Current Research Programs
- Building on the Successes & Addressing the Next Series of Challenges for the R&D Community
Causes of Damage to Pipelines

Outside force damage is the single greatest cause of pipeline failures
Mechanical Damage is single largest cause of on-shore pipeline damage
Damage Prevention – Why is This so Challenging?

- Substantial mileage of all SYSTEMS
  - 170,000 miles of hazardous liquid lines
  - 295,000 miles of gas transmission lines
  - 1,900,000 miles of natural gas distribution lines

- Varying needs - unique conditions for each operator

- Monitoring Frequency and timing; resource limitations

- Accuracy and reliability of databases (upkeep)

- Sensitivity of Measurement systems

- Inherent difficulty in effective communication with multiple stakeholders and existing databases – DIRT, One Call, etc.

- “If You Build it They Will Come” – Increasing Encroachment
Damage Prevention – Desired Solution

- No single technology can address all pipeline issues
  - Tiered approach
  - Combination of multiple technologies

- GOAL: Develop one single, automated system, service or suite of technologies developed to apply over the entire pipeline system network to address:
  - Damage Prevention
  - Leak detection
  - Changed Conditions
  → RAM Program
Current Operational Practice

- Light aircraft (ex. Cessna 172)
- Flown low-and-slow (~500 ft AGL, 100 kts)
- Single pilot, sometimes with an observer
- No automation – pilot/observer looks out the window
- Calls in any threats observed

Benefits:
- Reliable
- “Real-time”

Costs:
- Safety of pilot, aircraft
- Time-consuming
- Only “sensors” are pilot’s eyes
- No documentation of ROW state
- Coverage of ROW is not continuous

Photo credit: Prasetyo, M. Ector
RAM Program Vision

Realize enhanced aerial surveillance of the ROW through a suite of cost-effective sensors and technologies to prevent infrastructure damage.

Project Objective

▪ Identify, validate and advance automated monitoring technology
▪ Implement near term solutions on manned aircraft - long term view to satellite and unmanned surveillance

Integrate sensors and technologies:
✓ Airborne Threat detection systems
✓ Near real-time detection & reporting
✓ Long range communications
✓ Multiple data systems
✓ Image archiving & management
✓ Predictive Modeling

Scope – Automated Detection

▪ ROW Encroachments/intrusions
▪ Machinery/spills underneath tree canopy
▪ Ground disturbances, erosion, etc
▪ ROW Leak Detection – Gas & Liquid Hydrocarbons
Benefits of RAM and Related R&D

- Enhance community safety and environmental protection
- Increase pilot safety
- Increase pipeline integrity, security and reliability
- Significant improvement to efficiency and effectiveness of monitoring pipeline ROWs
- Augment ability to detect and respond to unauthorized excavations
- Reduce third party encroachments and incidents
RAM Program Overview

**Goal:** Real-time Detection and Reporting

**Design Drivers Set by End-State Goal:**
- persistence: 24 x 7 x 365
  - drives solution to satellite(s) or large fleet of aircraft
- resolution: <1 m (?) from orbit
- reporting: <1 min (?)
  - drives solution to on-board processing or fat comm pipe

**Components:**
- **Instruments**
- **Algorithms**
- **Resolution at flight altitude:** <1m @ 400 ft
- **Ground-based processing** ~24 hrs
- **On-board processing** ~1 hr
- **On-board processing** ~5 min
- **<1m @ 5,000 ft**
- **<1m @ 20,000 ft**
RAM Program - Concept of Operations

- Suite of sensors mounted on various aerial platforms to **detect** machinery threats (as well as other threats such as leaks and ROW changes)

- Automated recognition and identification of threats and **process** data on board aerial platform

- Via communication link (wireless, radio) **notify** operations center and/or designated field locations of threat with appropriate alarm indicating severity

- Download and **archive** data
Successes of our

CURRENT RESEARCH
Damage Prevention - Machinery Threat

- **Objectives**
  - Develop **technology** to enhance detection encroachment or intrusion along ROW
  - Bulldozers, backhoes, drill/augers, and scrapers
  - Improve efficiency, coverage and cost-effectiveness of patrol

- **Approach**
  - Automate **documentation** and **detection** tools
  - Enhance current practice (manned patrols)
  - Develop algorithms and prototypes for future flight systems

- **Schedule**
  - Phase 1: Collect data, evaluate sensors, develop algorithms & concept of operations (completed)
  - Phase 2: Validate algorithms, prototype and test system in field (current focus)
  - Phase 3: Refine, produce, and verify flight system
Threat Detection: Status

- Developed an easily modifiable end-to-end proof-of-concept system for collecting imagery, consistently finding most threats, and objectively evaluating the system performance.
- Developed prototype image collection system, using COTS camera with custom firmware and in-wing mount.
- Worked with BP to conduct flight activities: collected ROW and Threat imagery, demonstrated system capabilities.
- Threat detection algorithms were significantly improved, with most of the threats due to heavy digging equipment being correctly tagged (however, the false alarm rate is high).
Threat Imaging Technology Demonstrated

Wing-mounted visual imaging camera – configure for current platform
Algorithm Successfully Identifies Threats

Algorithm accurately identifies threats at high rate of detection
A good test case – no false positives!
Damage Prevention – Leak Detection

- Technologies for detection above ground are commercially available

- Project focused on *underground* detection
  
  - Developed an algorithm that automates hyperspectral airborne image analysis for underground gas leak detection utilizing plant stress response to CO2
  
  - Automation algorithm matches results of manual analysis (using COTS ENVI software) almost identically

  - *The plant stress mapping technology is of high readiness*
Leak detection via plant stress response

Manual analysis results

Plant stress spots correspond to measured CO₂ flux maxima
Semi-automatic notch depth analysis results

Black and white:
raw results

Colored:
brightness ranges mapped
to 6 color set

Red indicates leak or false positive

False positives can be discriminated based on sharpness of edges and/or using high resolution photographs
Information Gathering

- Request for Information, RFI, announced through DOT – PHMSA
- FedBizOps RFI #DTPH56-09-1000001
- Solicited input on available technologies relevant to RAM program
- Has been, and is continuing to be, very successful
- 36 Responses to date, extended through 2010, and possibly through project life cycle

- Responses covered a range of sensors and technologies e.g.,
  - Full spectrum hyperspectral
  - Light Detection and Ranging
    - Morphology measurements (-vs- gas constituent detection via differential absorption)
  - Synthetic Aperture Radar (SAR)
  - Polarimetry
  - Magnetometry
  - Data Fusion / Hybridization
  - Imagery / Hyperspectral / Lidar / SAR

- Responses are still solicited!
Building on our successes… addressing the next

CHALLENGES
Challenges and Additional R&D Needs

Sensors

- What are the *minimum* requirements?
  - Type
  - Resolution
  - Calibration & maintenance requirements
  - Payload limitations

- Sensor and computer miniaturization

- Automated sensors that detect machinery in various environments, terrains, and background conditions
  - Snow, grass, dirt, sand
  - Mountain, swamp, forest and variable terrains
  - Under tree canopy
  - Off-shore
Challenges and Additional R&D Needs

Data Processing and Communications

Near-real time to real time
- Detection, analysis & processing; on-board systems
- Multiple sensors
- Dissemination and appropriate notification

Over the horizon, high band-width communications
Full integration with aircraft and ground systems
Data management and archiving challenges

Human factors

Evaluating Multiple Platforms
- Manned – near term focus
- Unmanned – mid to long term goal
- Satellite – long term goal
RAM Program plans

- In 2010, the program will focus on:
  - Continued development and validation of machinery threat detection technologies
  - Development of a flyable prototype system
  - Continued evaluation and assessment of elements identified through the RFI process
RAM – Other Potential Benefits

- Enhance localized aerial surveillance
- Focus surveillance during spill/event
  - Marine oil spill, wildfires, hurricanes
- Security surveillance
  - Refinery, tank farm or marine terminals
- Threat detection and security for other linear industries or critical infrastructure
  - Water, electric, highway, rail, communications
PRCI, in collaboration with NASA, has successfully implemented a research program that is focused on overcoming the key gaps for automated right-of-way monitoring:

- Developing and testing systems capable of detecting heavy equipment threats and underground leaks
- Defining operational requirements

- We are not focusing on elements that are easily procured

- Significant challenges remain to be addressed

- The fundamental technologies being developed and tested are of broad value to NASA and the nation
RAM Program

- Questions