Automated Monitoring of Pipeline Rights-of-Way

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Chad R. Frost
Manager, Autonomous Systems and Robotics
NASA Ames Research Center
Moffett Field, California
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
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

Scope – Automated Detection

- ROW Encroachments/intrusions
- Machinery/spills underneath tree canopy
- Ground disturbances, erosion, etc
- ROW Leak Detection – Gas & Liquid Hydrocarbons

Integrate sensors and technologies:

- Airborne Threat detection systems
- Near real-time detection & reporting
- Long range communications
- Multiple data systems
- Image archiving & management
- Predictive Modeling
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

RAM Development Path

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
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)
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!
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