3.5 Intelligent Unmanned Monitoring of Remediated Sites

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Abstract

The U.S. Department of Energy (DOE) is tasked with cleaning up thousands of locations that have been seriously contaminated in the past. More than 5,700 known DOE groundwater plumes have contaminated over 600 billion gallons of water and 50,000,000 cubic meters of soil. The migration of these plumes threatens local and regional water sources, and in some cases has already adversely impacted off-site resources. In addition, DOE is responsible for the remediation of numerous landfills at DOE facilities. These landfills are estimated to contain over 3,000,000 cubic meters of hazardous buried waste, some of which has migrated to the surrounding soils and groundwater.

Unfortunately, all currently available hazardous waste monitoring technologies are barely adequate or completely unacceptable, due to their high costs, long turn-around times, and their need for experts (who are available only in a limited supply) to analyze the results. The methods presently used for assessing contamination in soil, groundwater, and other environments include either taking samples and transporting them off-site to a laboratory for analysis or installing (usually only temporarily, using a truck-mounted unit) a Raman spectrometer or other suitable detection instrument on-site. Raman spectrometry is used to identify organic contaminants, such as chlorinated hydrocarbons (*e.g.,* trichloroethylene [TCE], tetrachloroethylene [PCE], and dichloromethane [methylene chloride]) and fuel hydrocarbons (*e.g.,* benzene, toluene, and various xylenes, collectively referred to as BTEX).

Generally, commercially available Raman spectrometers work well at producing spectra that hold important evidence about organic contaminants. They also hold promise for determining the amounts of each of several different contaminants, even when they occur together, or when they are mixed with a variety of other materials. Unfortunately, expert analysis of these data has always been necessary to get valid results, and experts are often unable to see significant signals when those signals are weaker than the noise signals that inevitably accompany them.

We are addressing this problem through the development of a cost-effective system for autonomous, real-time characterization and quantitative analysis of hazardous chemicals in a variety of matrices.

Our automated software-based analysis technology will significantly augment the capabilities of existing spectrometers, and, in the process, will greatly reduce or totally eliminate many of their most significant limitations. Our spectral recognition technology will permit many more measurements to be taken in a given amount of time, at much lower cost, and with greater accuracy than has ever been possible in the past.

Specifically, our technique, which uses advanced digital signal processing for spectrum analysis, will enable accurate, quantitative assessments in situations where the signal to noise ratio is less than 1:1.

One possible implementation of our technology includes a self-contained remote, on-site, continuous monitoring station. Running on solar power plus internal batteries, it can simultaneously monitor a number of probes contained in a cone penetrometer, inserted in the surrounding terrain, and can radio an alert at any time it detects more than a pre-set threshold level of contaminants at any of those probes. These pre-set threshold levels can be adjusted in the field, to adapt the unit to different standards of remediation for sites in different locales, or when regulatory requirements change.

The monitoring station could employ two separate spectrometers to produce both a Raman and a laser-induced fluorescent (LIF) analysis of the visible and UV spectra of the material surrounding the probes, thus enabling the software to use contaminant signatures from both Raman and LIF processes simultaneously—heightening both the sensitivity and reliability of the detection process.

In previous work, we demonstrated the feasibility of automated analysis of spectral signals from pure samples of several typical contaminants. We fabricated and tested a prototype system by automatically analyzing Raman spectral data provided by Dr. Rossabi at the Westinghouse Savannah River Company. This data was taken in the Vadose zone at the 321 M site in the M area of the Department of Energy’s Savannah River Site.

This test demonstration proved the ability of our technology to detect the target contaminants (PCE and TCE) in isolation, and also demonstrated this approach's ability to identify the spectra of these contaminants in real-world noisy samples taken from a mixture of materials obtained from this typical remediation target site.

Our current work involves enhancing and optimizing the software, rendering it ready for commercialization, and construct a prototype instrument by incorporating our smart spectroanalysis software and commercially available light sources, spectrometers, and an industry-standard personal computer.

This project will enable an entirely new class of tools for toxic waste site evaluation and monitoring, without the need for trained experts or technicians.

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Overview

- Introduction
- Objective
- Approaches
- Project Description
- Results
- Future Plans
- Benefits & Applications

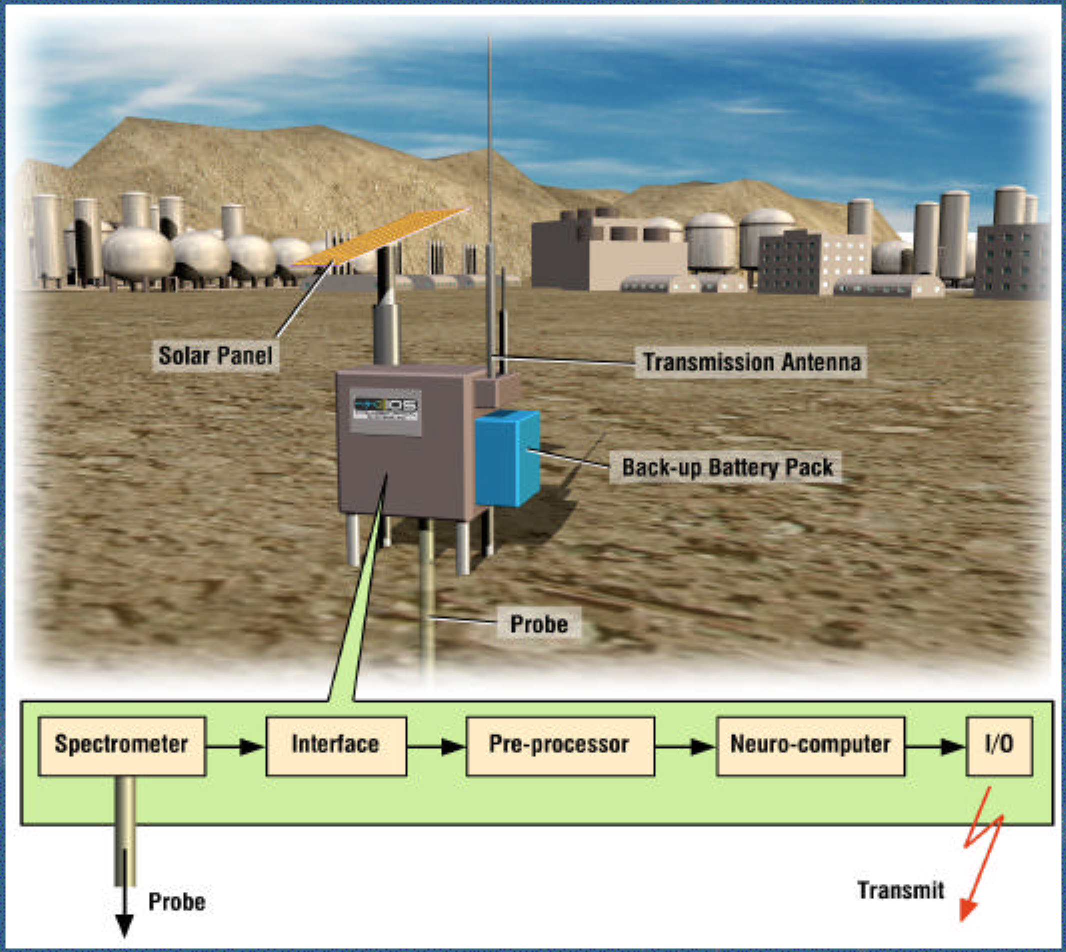
What is IOS?

- Founded in 1998
- Located in Torrance, CA
- Developing and commercializing optics-based sensing and monitoring products
- 36 employees, 12 PhDs
- Recipient of 11 SBIR/STTR Phase II Awards

Intelligent Unmanned Monitoring of Remediated Sites

Phase I
September 2000 to March 2001

Phase II
June 2001 to June 2003



The Problem

- Widespread environmental pollution
- Contamination of soil and ground water
- Thousands of locations nationwide
- 5,700 contaminated groundwater plumes
- 3,000,000 m^3 of buried waste
- 50,000,000 m^3 of contaminated soil
- 600,000,000,000 m^3 of polluted water

Project Objective

To develop a system that is

- smart
- cost-effective
- autonomous

for real-time

- characterization and
- quantitative analysis

of hazardous chemicals in a variety of matrices.

Current Monitoring Approach

- Most common scenario:
  - Take samples manually in the field
  - Transport samples to a laboratory
  - Off-line spectral analysis
  - Interpretation of results by an expert
- Alternative:
  - Down-hole probe with (Raman) spectrometer
  - Interpretation of results by an expert

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Problems with Current Approaches

- Available monitoring & characterization technology has one or more of the following problems:
  - Barely adequate
  - Slow
  - Labor intensive
  - Not-suitable for long-term (unmanned) operation
  - Low sensitivity and accuracy due to noisy spectra
  - Expensive

Desired Solution

- Unmanned monitoring
  - Autonomous decision making
- Long-term monitoring
  - Remote reporting and alarm
  - Built-in energy generator
- High accuracy and sensitivity
  - Overcome noise problems
  - Combine spectral info through data fusion

Our Solution

- Use multiple fiber-optic probes
- Use more than one spectrometric technique
- Data fusion for combining spectral info
- Accurate interpretation of noisy signals
- Real-time automatic spectral analysis & interpretation

Phase I Approach

Show the feasibility of combining digital signal processing and SSMART^{TM} software to analyze typical contaminants

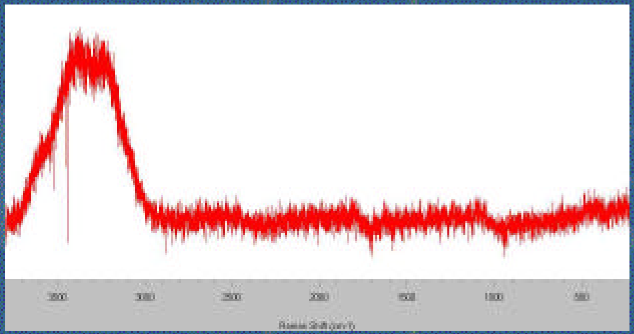
by analyzing spectra of pure chemicals

and spectra of chemical mixtures

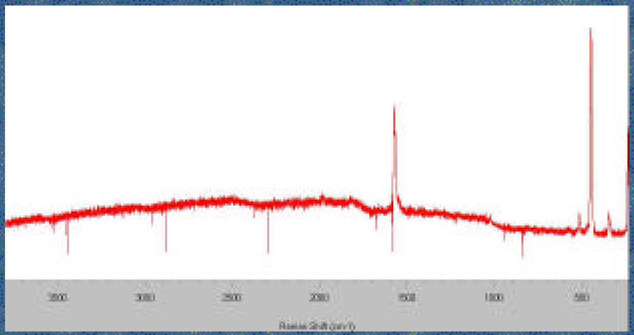
Pure Samples

For spectra of pure TCE, pure PCE, and pure water (Raman spectra supplied by Dr. Dan Borchardt of UC Riverside)

Training and testing accuracy were each 100%



Raman spectrum for pure water

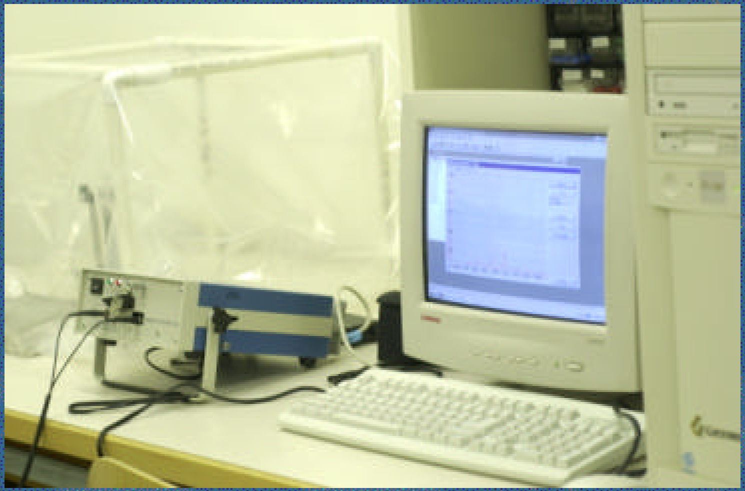


Raman spectrum for pure TCE

Data Taken in House

For spectra of

- benzene
- chloroform
- isopropanol
- PCE
- TCE
- toluene
- xylene

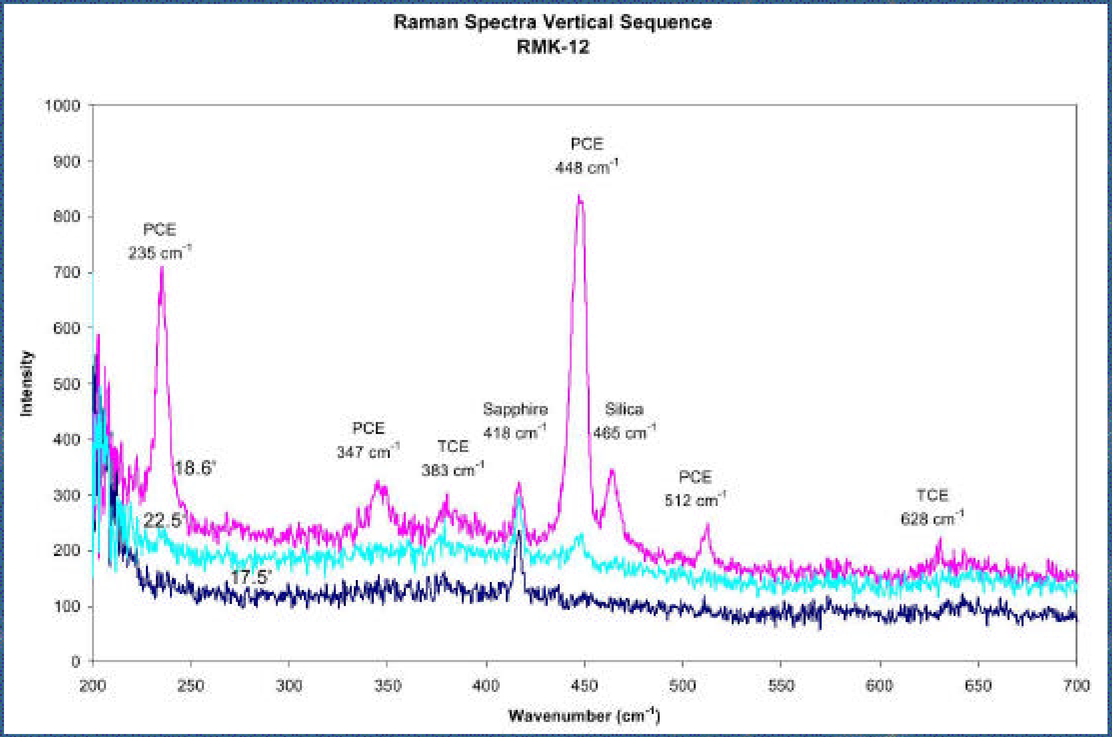


SSMART recognized all seven substances

Data from Savannah River Site

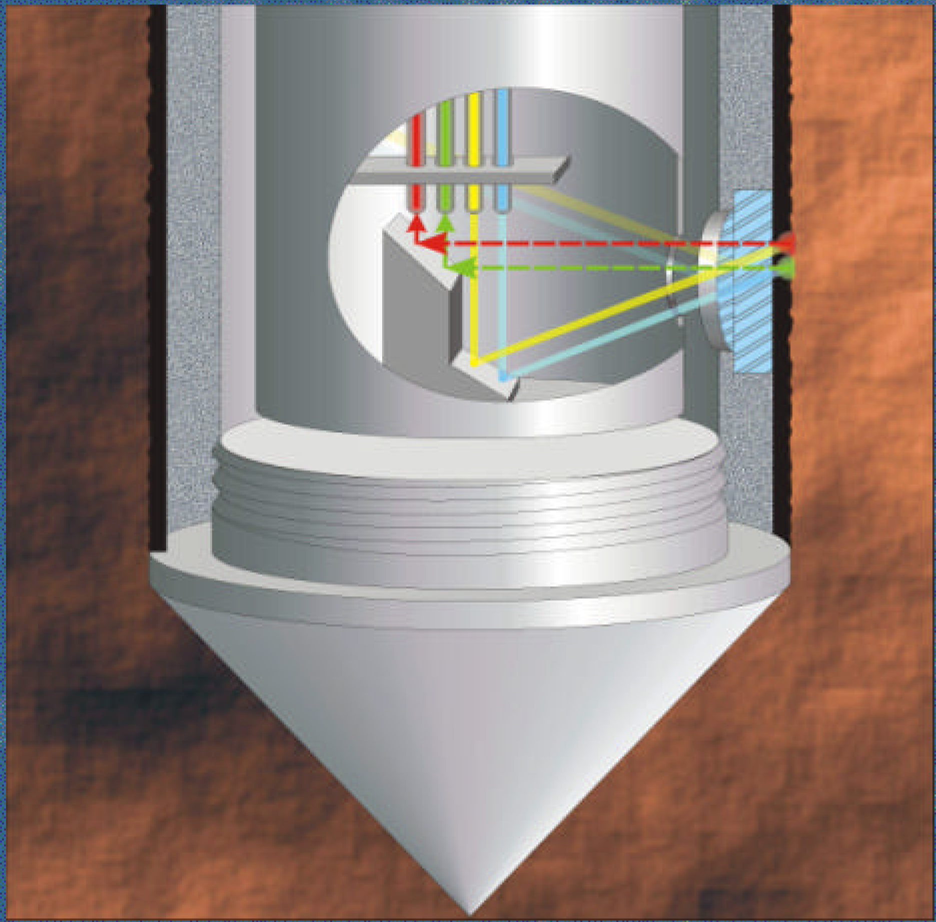
For data taken in the Vadose zone at the 321 M area, SRS, supplied by Dr. J. Rossabi

SSMART results were 81% for the training facts and 75% for the testing facts



Phase II Objectives

- Performance:
  - 95% recognition accuracy for compounds in isolation
  - 90% for compounds in combination
- Make system user-friendly
- Determine number of probes/system
- Ruggedize prototype
- Field test prototype
- Begin agency approval process



Goals for Phase II

- Develop a user-friendly software package
  - Advanced signal processing for accurate real-time spectral interpretation
  - Enable interfacing with any spectrometer
  - Enable self-calibration and self-monitoring
  - Enable remote operation and reporting

Some Specific Tasks

- Render system easy to use

  to reduce need for trained personnel, to improve response to critical situations
- Render the software spectrometer independent
- Obtain ruggedized spectrometers
- Design different probe configurations

Applications

- Environmental
  - Landfills
  - Contaminated sites
  - Storage facilities
  - Wells, soil, fields
  - Water quality, water treatment
- Commercial
  - Industrial processes
  - Food supply
  - Condition/quality of jet fuel, turbine oil, lubricants
- Civil and Military
  - Biological/chemical threat detection and monitoring