Use of the JPL Electronic Nose to Detect Leaks and Spills in an Enclosed Environment

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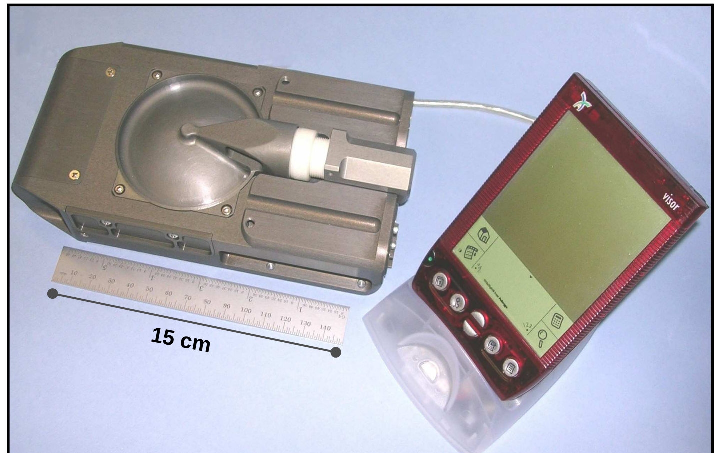
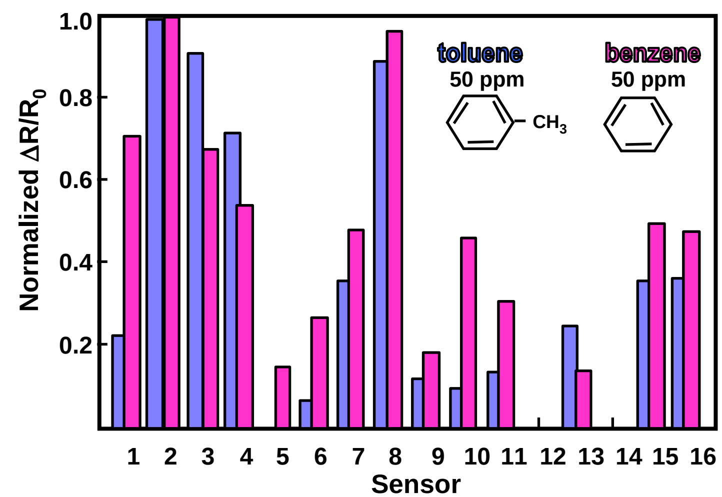
The JPL Electronic Nose

- An electronic nose is an array of semi-selective chemical sensors. The JPL ENose is 32 sensors which change electrical resistances when environmental composition changes.
- The sensing array responds in “fingerprint” patterns to a broad suite of target analytes. Fingerprints are deconvoluted for id and quantification.
- The JPL ENose is capable of providing rapid, early identification and quantification of target chemical species.
- Targets include leaks or spills of selected compounds, Hg, SO_2 and possibly heating insulation which signals electrical fires.
- The JPL ENose can be used to monitor cleanup processes.

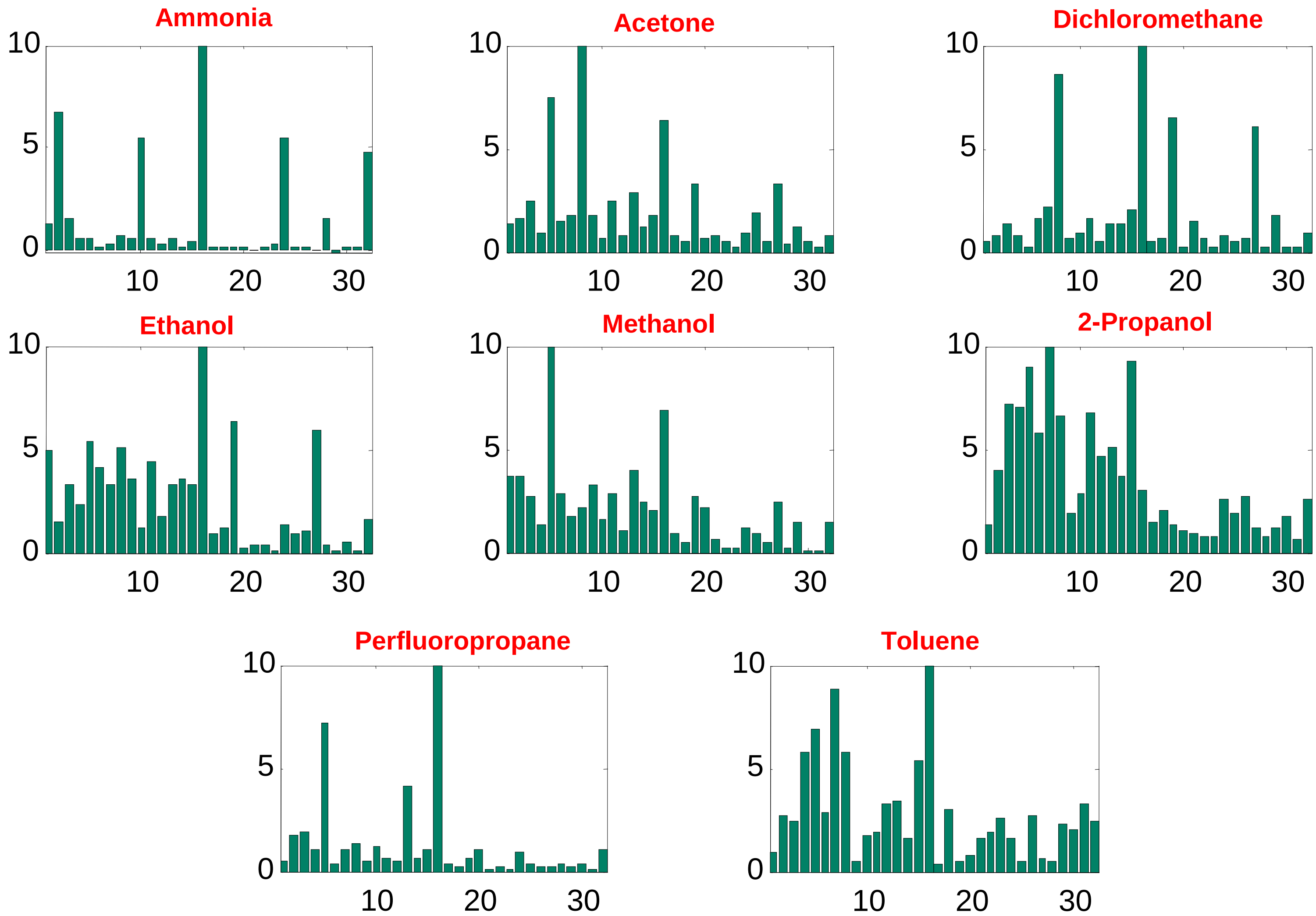


The Second Generation JPL ENose. The volume of this design is ~760 cm^3, and the mass is ~800 g not including the computer. A PDA can be used to record data for later analysis or to transmit data to another computer for analysis. An ultra-micro computer (386 or higher) can be used for on-board real-time data analysis.

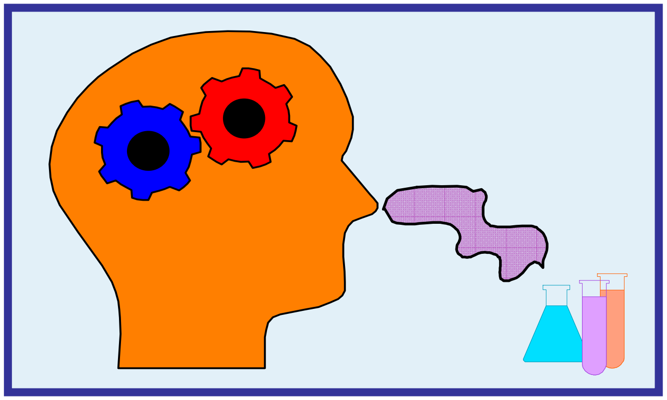


Experimental Response of Sensors

Response of 3rd Generation Polymers to Tier 1 & Tier 2 Analytes



Real Time Air Quality Monitoring



HUMAN NOSE

- array of hundreds of sensors
- organic sensors
- broad band capability
- trainable to new odors
- data acquisition in the brain
- analysis by true Neural Network processing; pattern recognition

LIMITS ON HUMAN NOSE

- fatigue
- odor adaptation
- insensitivity to some species
- toxicity of some contaminants

JPL ELECTRONIC NOSE

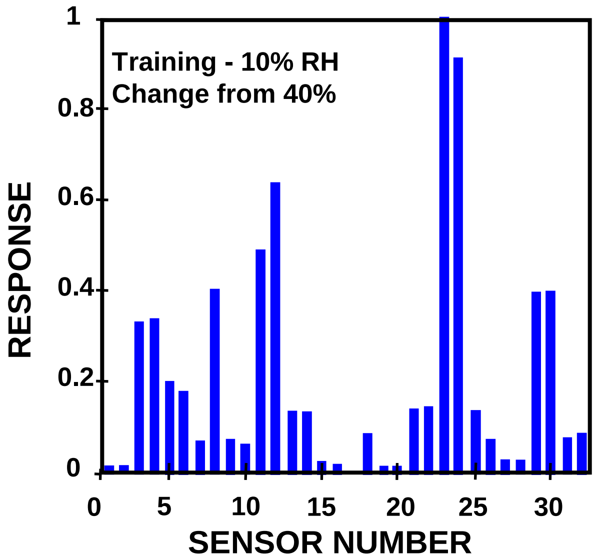
- array of a few tens of sensors
- thin film polymer based sensors
- broad band capability
- polymers selected to respond to particular compounds
- trainable to new analytes
- data acquisition by computer
- data analysis by computational methods and pattern recognition

LIMITS ON ENOSE

- insensitivity to some species
- good only for a limited set of analytes

Response Patterns Of Mixtures

Simple mixture responses are linear combinations of single analyte response



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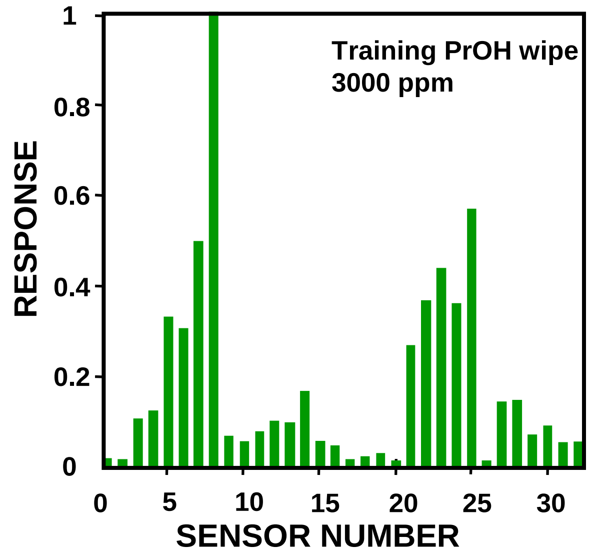

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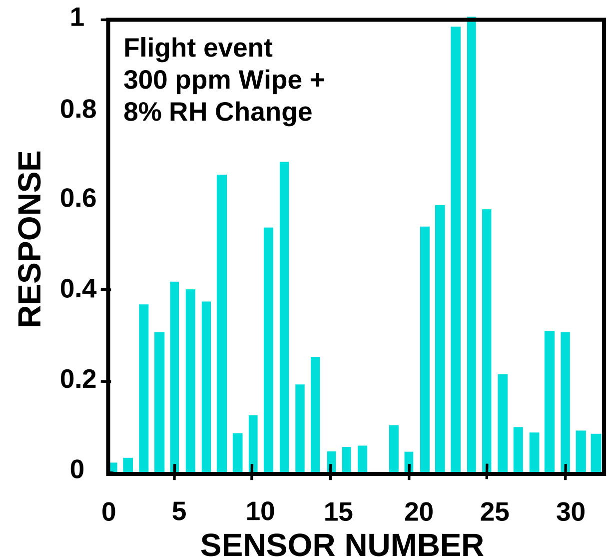


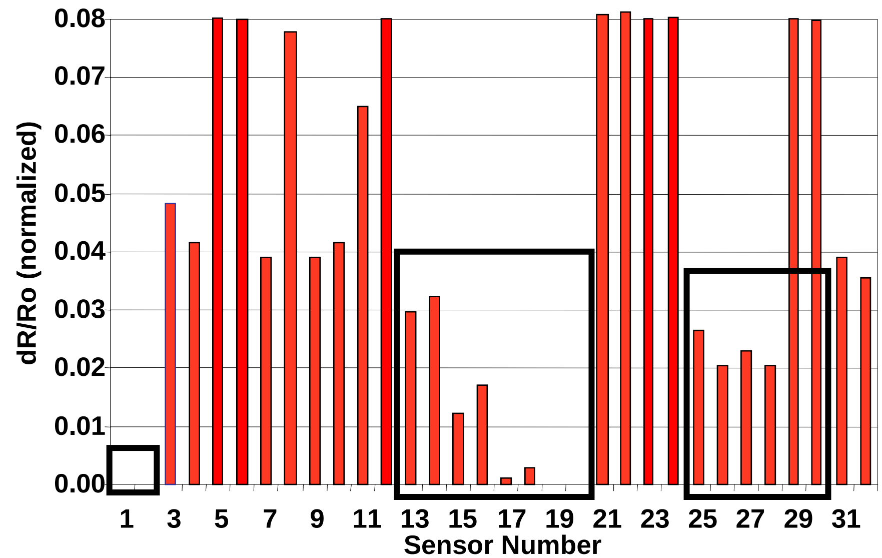
During the 1998 Flight Experiment, daily markers of propanol/water wipe events, were recorded to allow verification that the device was operating normally. All these events were identified and quantified as such. The event at 306.95 is identified as a combination of wipe and humidity change; the pattern is a combination of the two training sets.

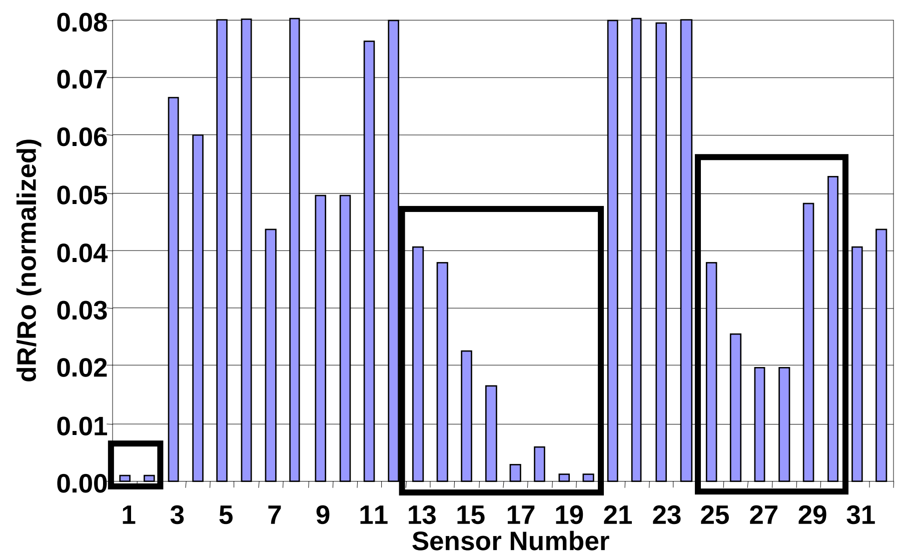
Response Patterns of Mixtures

Complex odors and mixtures may be treated as single analytes

Complex mixtures which do not change composition can be treated as a single analyte by an electronic nose. In the absence of other chemical species, or in the presence of an unchanging background, the complex mixture will yield a single array response pattern.

This figure shows how Coca-Cola and Pepsi-Cola have similar but distinguishable array response patterns





Why NASA Needs An Event Monitor

Events Affecting Air Quality During Shuttle, Mir & ISS Missions

Red – ENose is trained to detect these events
Blue – ENose could be trained to detect these events

Shuttle

- Teflon sleeve pyrolyzed by electrical short (STS-28)
- Wire burnt beneath humidifier (STS-6)
- LiOH dust escaped from CO2 removal canisters
- Brown dust released from waste management system
- Combustion products from electronics pyrolysis in 2 data display units (STS-35)
- Formaldehyde pollution from pyrolysis of motor housing in refrigerator (STS-40)
- Undersized capacitor overheated in laptop causing odor (STS-50)
- Microbial production of methyl sulfides from liquid waste (STS-55)
- Mir airlock adapter coating strongly off-gassed (STS-89)

Mir

- Frequent leaks of ethylene glycol from cooling loops into air
- Formaldehyde escaped containment on Mir-18
- Oxygen candle fire produced various thermal degradation products, e.g. benzene (Feb 97)
- Overheating BMP beds produced health threatening levels of CO (Feb 98)

ISS

- Crew sickened in FGB during poor ventilation, probably from rebreathe of exhaled air/CO2 (Flight 2A.1)
- Freon 218 leaks from SM air conditioner (Apr 01 to Mar 02)
- Extremely high methanol in a sample of FGB air; exact source never determined (Aug 01)
- METOX canister regeneration caused noxious air-many pollutants in air (Feb 02)
- Formaldehyde periodically exceed long-term limits, when debris restricted ventilation (mid 02 to Feb 03)
- Strong solvent-like odor from Elektron oxygen generator after repair work (Mar 04)
- Potential acid preservative aerosol escape from Russian urinal problem (Exp 10/Feb 05)
- Electrical odor traced to lamp on Service Module (Exp 10/Mar 05)
- Triol coolant leak from fittings in Service Module (Exp 14/Aug 06)
- Elektron incident; CO up to 7ppm; HCL,HCN above 1 ppm; smoke & solvent smell reported (18 SEP 06)

NASA Requirements for Air Quality Monitoring

Monitor cabin environment with time stamped measurements and rates of change

- **Major constituents** - "near-continuous" monitoring

  N_2 O_2 CO_2 H_2O

  H_2 CH_4 CO

- **Trace contaminants** - less frequent monitoring required

  ~ 40 organic compounds

- **Event Monitoring** - rapid response time
  - pyrolysis markers - CO HCN HCl
  - marker compounds for electronics overheating
  - monitoring for sudden release from fluid systems, experiments, EVA, waste
  - follow progress of decontamination after an event

based on AEMC *Requirements for Technology Development*, 1998, Section 5

Cabin Air Quality Event Monitoring

JPL ELECTRONIC NOSE

FUNCTIONS

- **Incident monitor for targeted contaminants exceeding targeted concentrations. Identify and quantify.**
- **Monitor for presence of compounds associated with fires or overheating electronics**
- **Monitor clean-up process**

CHARACTERISTICS

- **Low mass, low power device**
  First Generation ***1.5 kg; ~ 2 L; 1.5 W avg, 3 W peak***
  Second Generation ***< 1 kg; < 1 L; 1.5 W avg, 3 W peak***
- **Requires little crew time for maintenance and calibration**
- **Detects, identifies and quantifies 24 selected chemical species at or below 24 hour SMAC**

Electronic Nose For Space Station

ELECTONIC NOSE:

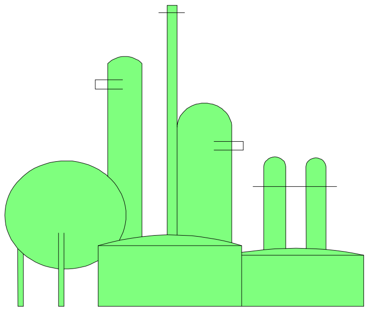
- **Incident monitor - real time air quality monitoring**
- **Identify and quantify target compounds at SMAC level**
- **Low mass, low power device**
- **Requires little crew time for maintenance and calibration**

	Analysis Time (min)	Concentration of Constituents	Discrimination of Constituents
ENose	.5 - 15	0.01 - 10,000 ppm	good for target set
GC-MS	10 - 100	< 10 ppb	very good
Optical	1 - 5	0.01 - 2000 ppm	good for target set
VOC	1 - 5	.1 - 2000 ppm	poor
FID	1 - 5	.1 - 50,000 ppm	poor
Smoke Alarm	.5 - 5	1 - 10 ppb	none

Why Use the ENose?

- Fills gap between an alarm (no id or quantification) and complex analytical instruments
    - ID and quantification of trained-for chemical species
    - Wide dynamic range: fractional ppm to 10,000 ppm
    - Array based sensing; can be trained to detect new species and training data uplinked
    - Runs continuously (30 to 360 data points/hr) and autonomously
- Simple design, robust, rugged, microgravity-insensitive
- Minimal crew interaction required
- Requires no consumables
- Low mass, volume, power
- Readily integrated with larger devices and with monitoring/control systems
- Can analyze volatile aerosols as well as vapors

Other Electronic Nose Applications



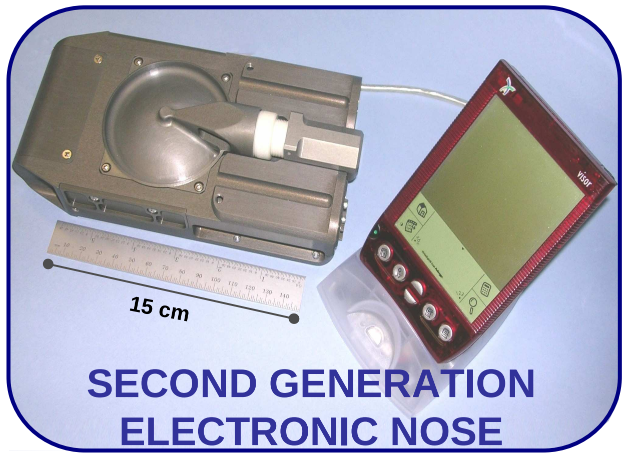
INDUSTRIAL MONITORING AND PROCESS CONTROL

Identity and condition of raw materials, leaks and buildup of toxic compounds; Monitor food processing

MILITARY APPLICATIONS

air quality monitor, detection of explosives and other hazards

SPACE STATION ENVIRONMENTAL MONITORING



SECOND GENERATION ELECTRONIC NOSE

PLANETARY EXPLORATION

Study planetary atmosphere to determine constituents and fluctuations

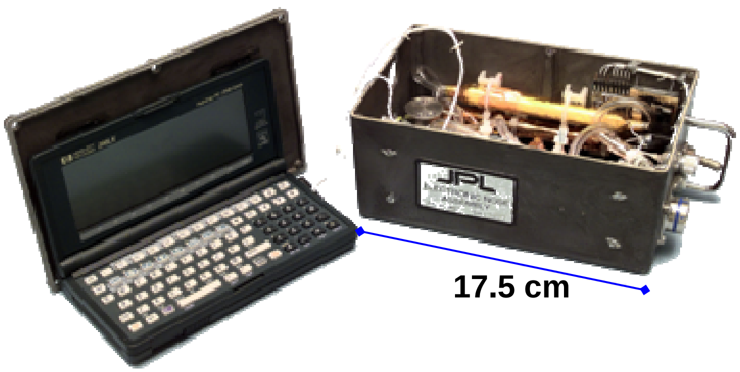
OTHER ENVIRONMENTAL MONITORING

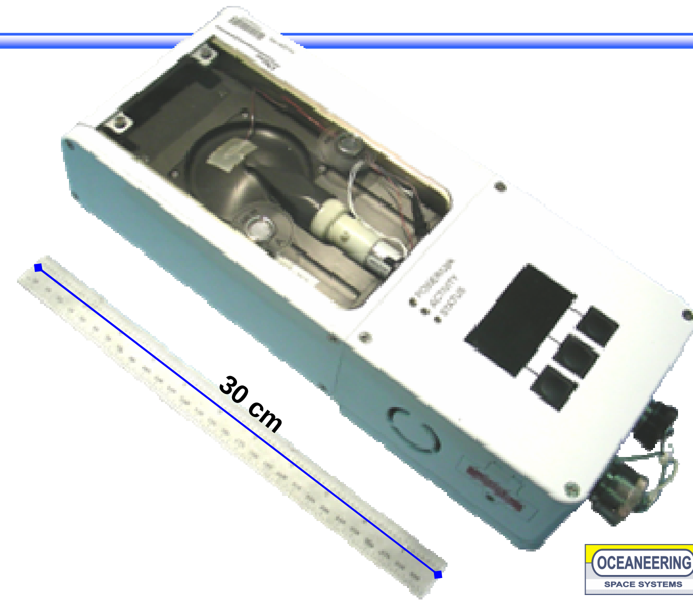
Air quality in buildings, aircraft. Presence of toxic materials in enclosed spaces (mines, tunnels, etc.)

MEDICAL APPLICATIONS

Diagnosis through breath or body fluid analysis; remote monitoring of patient condition

Three Generations Of Autonomous ENoses





Generation 1
Experiment on STS-95, TRL 6-7
funded by AEMC

Volume: 2000 cm^3 inc. computer

Mass: 1.4 kg including computer

Power: 1.5 W ave., 3 W peak

Detect/ID/Quant 10 compounds at 1 hour SMAC. No real-time data analysis; data acquisition and device control with HP 200LX computer.

6 day flight experiment successful.

Generation 2
Ground Testing, TRL 5-6
funded by AEMC

Volume: 750 cm^3 w/o computer

Mass: 800 g w/o computer

Power: 1.5 W ave., 3 W peak

Detect/ID/Quant 21 compounds at 24 hour SMAC. Data acquisition and device control possible with PDA computer; real time data analysis with ultra micro computer.

Extensive ground testing in environmental chamber.

AEMC requested that Gen 2 functions be transferred to Gen 3.

Generation 3
Tech. Demo. on ISS, TRL 4
funded by AEMC

Volume: 3.6 L inc. computer

Mass: 3 kg inc. computer

Power: 8 W ave., ~ 14 W peak

Detect/ID/Quant 10 compounds at defined concentrations, including Hg, SO_2. Deconvolute mixtures, id unknowns by functional group.

Data acquisition, device control, real time data analysis, display included.

Extensive ground testing in environmental chamber; then six month test on-orbit.

Third Generation ENose

Sensor Unit and Interface Unit Subsystems

ENose Sensor Unit (JPL)
Instrument Core / Sensing

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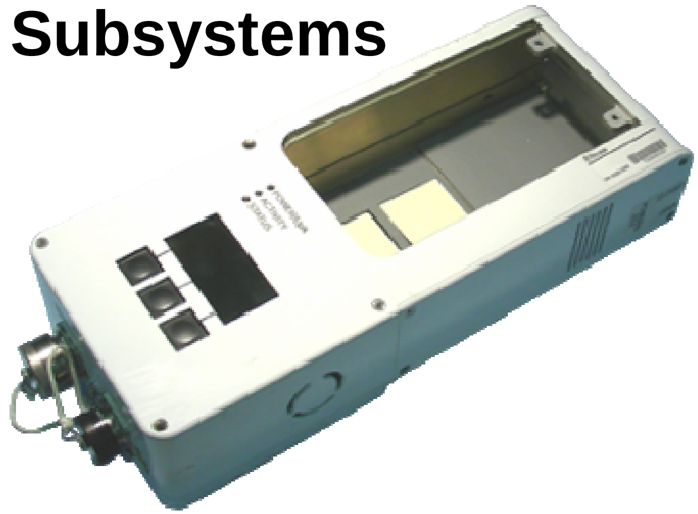

ENose Interface Unit (Oceaneering)
HW & SW Connection to ISS

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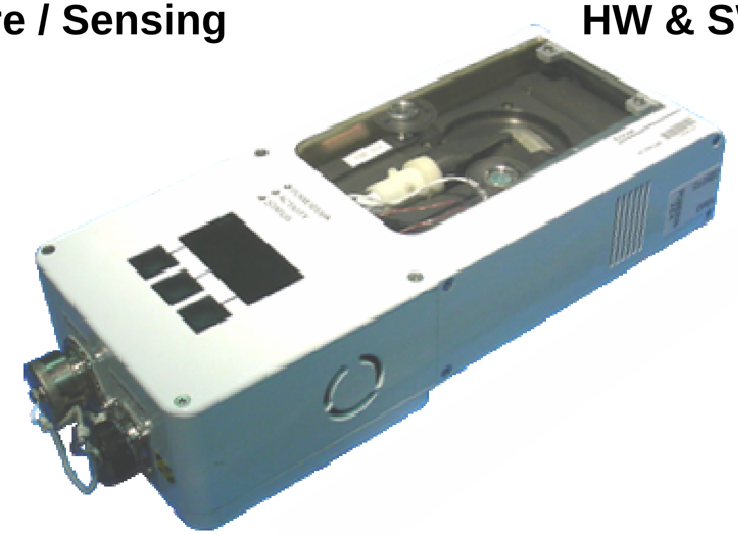
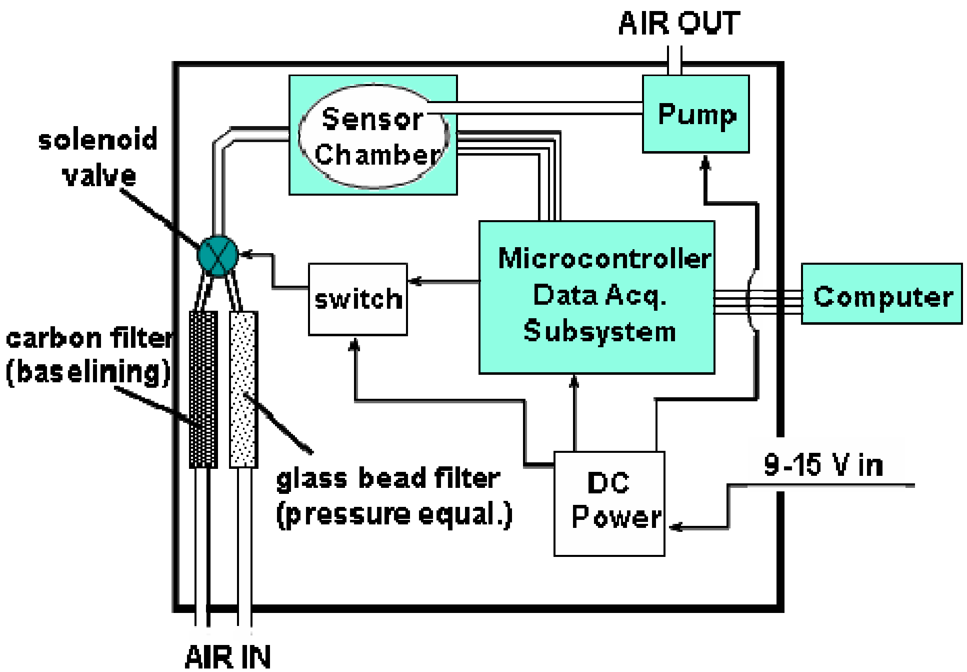
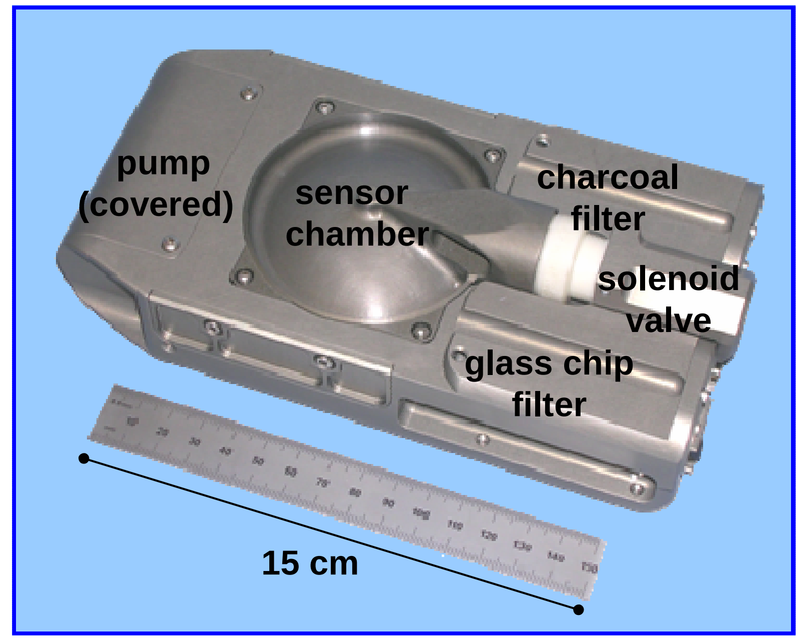


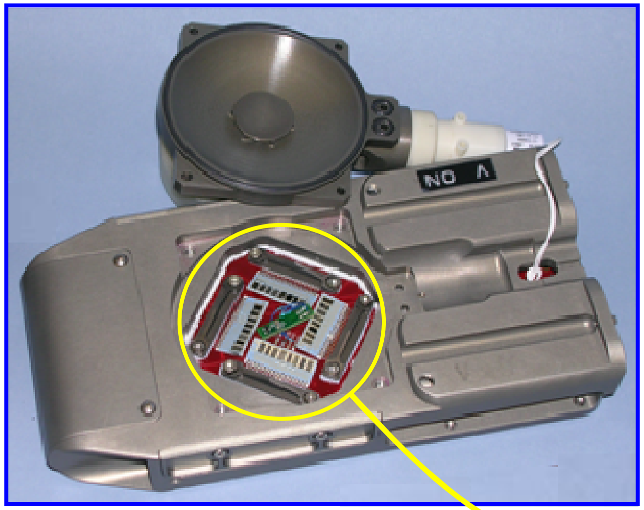
Third Generation ENose
Complete Experimental Instrument

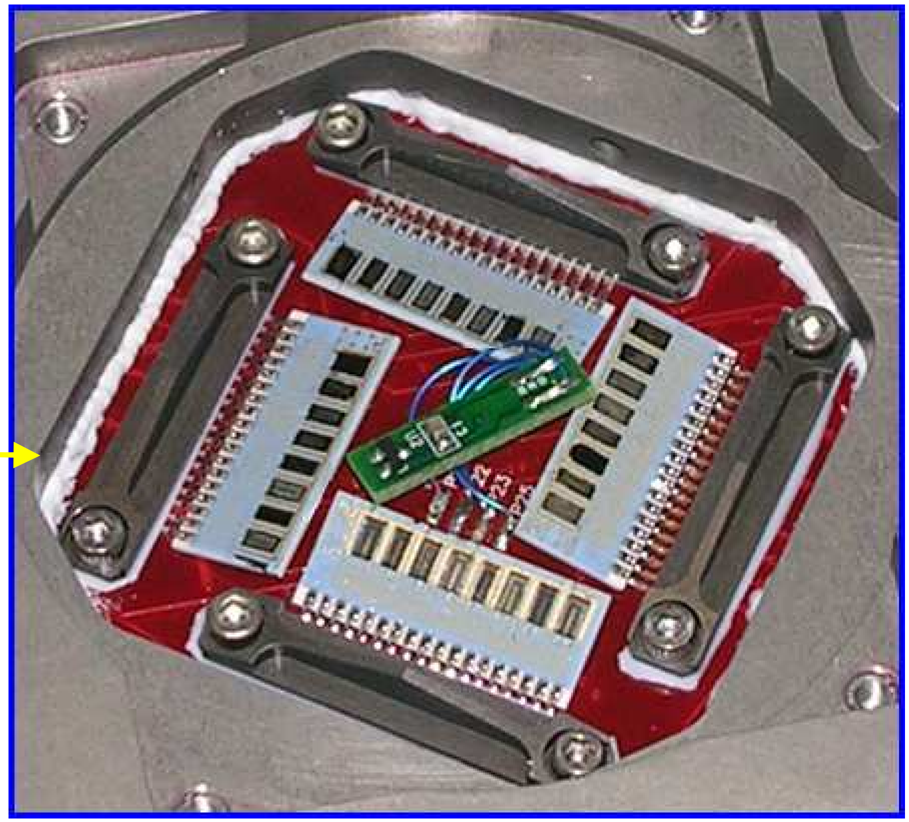
The JPL Electronic Nose





ENose Sensing Array





- Polymer loaded with carbon black for electronic conductivity
- Operate at 28-36 ^{o}C
- Sensor set selected to detect 20 organic and a few inorganic compounds

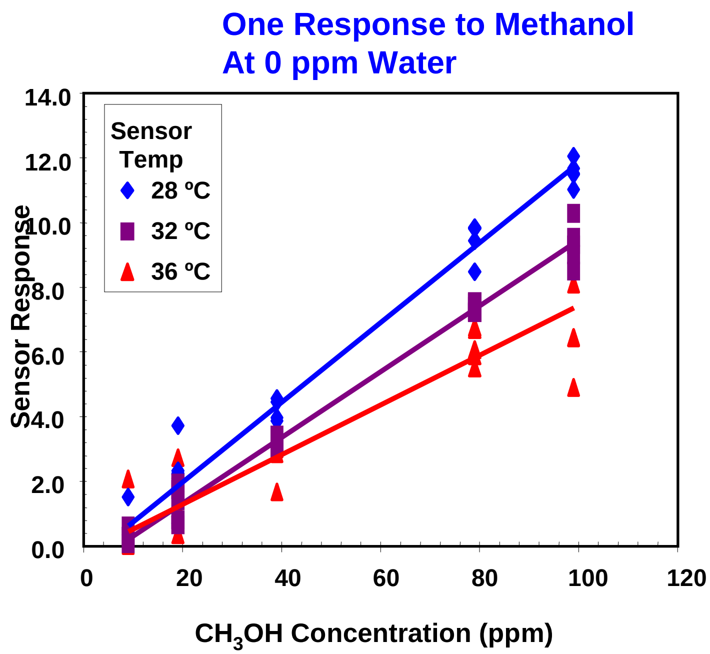
The JPL Electronic Nose

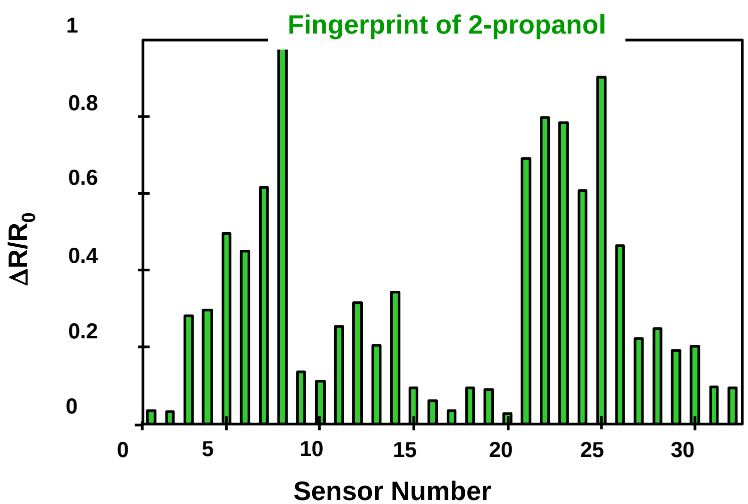
Analytes for Technical Demonstration Onboard ISS

	ANALYTE	CONC (ppm)	QUANT. RANGE (ppm)	JUSTIFICATION	24 HOUR SMAC (ppm)	ODOR THRESHOLD* (ppm)
TIER 1	Ammonia	5	1.6 – 15	Thermal control system external coolant; potential leak into cabin	20	50
	Mercury	0.01	0.003 – .03	High profile; used in ISS Hg vapor lamps and certain payloads	0.002	odorless
	Sulfur Dioxide	1	0.3 – 3	Thionyl chloride battery leakage potential	TWA = 2 STEL = 5	3
TIER 2	Acetone	270	90 – 810	Frequently detected in ISS atmosphere	200	20 – 600
	Dichloromethane	10	3 – 30	Always detected in ISS atmosphere	35	200 – 300
	Ethanol	500	166 – 500	Frequently detected in ISS atmosphere; ECLS concern	2000	10
	Freon 218	20	6 – 60	Russian A/C coolant; leaks have occurred; ECLS concern	11,000	na
	Methanol	10	3 – 30	Frequently detected in ISS atmosphere	10	10 – 100
	2-Propanol	100	30 – 300	Frequently detected in ISS atmosphere; ECLS concern	100	20 – 40
	Toluene	16	5 – 50	Represents aromatic compounds; frequently detected	16	0.2 – 2
TIER 3	Formaldehyde	0.1	TBD	Prevalent off gas product; health concern; allergen sensitivity	0.1	0.5 - 1

* SOURCE: US Coast Guard, Chemical Hazards Response Information System; http://www.chrismanual.com/
National Institutes of Health, Hazardous Substance Data Bank http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB

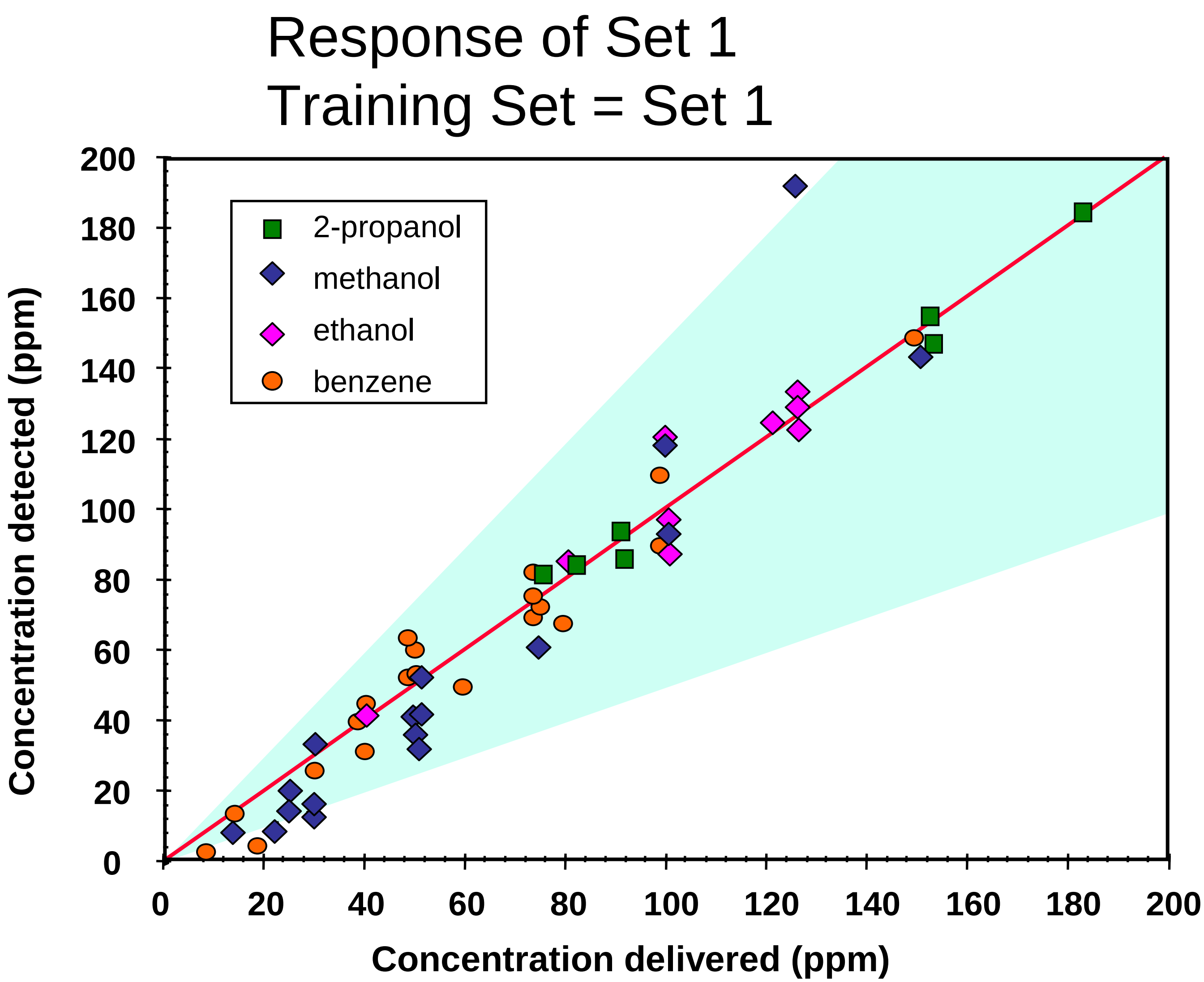
Training a Sensor Array



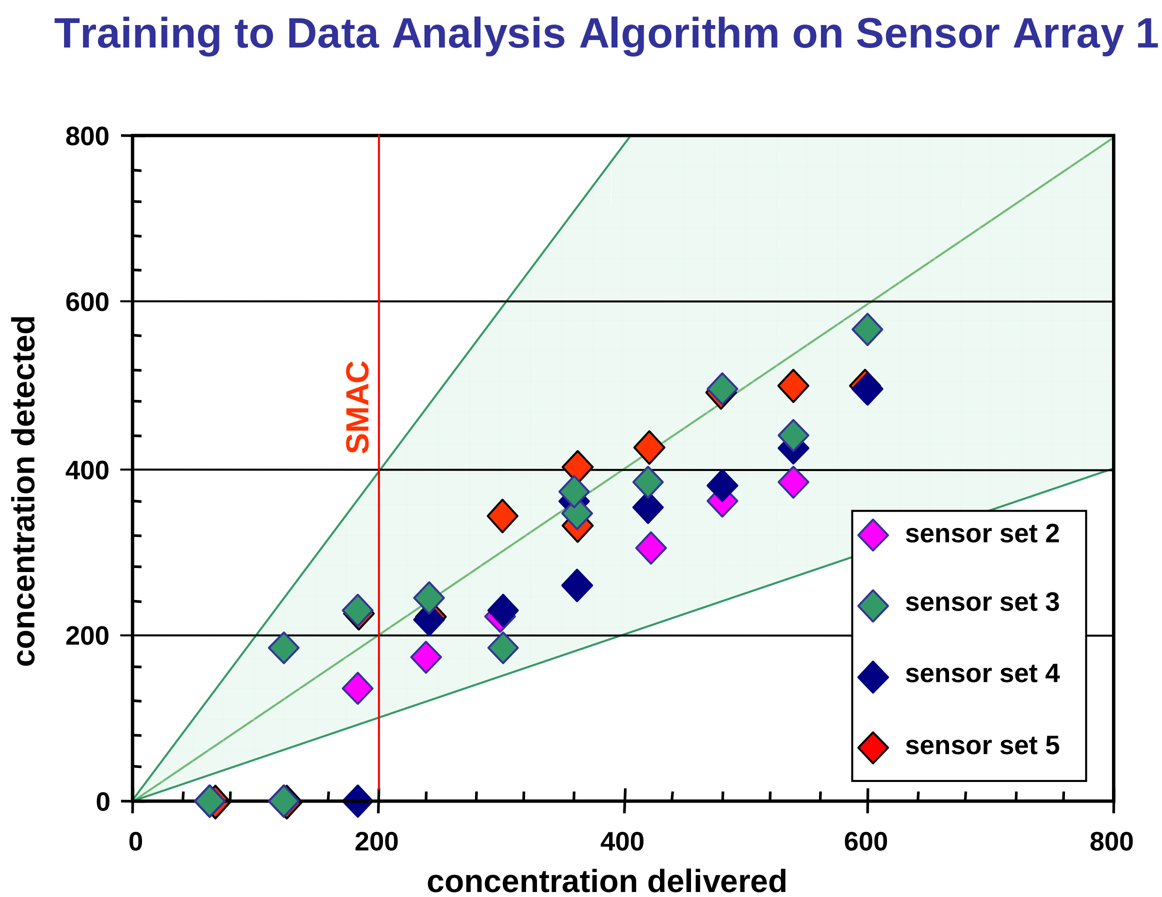


- Array is exposed to different analytes at different temperatures and background humidity
- For each analyte, the array is exposed to a range of concentrations repeatedly
- Response curves for each sensor are generated at different temperatures and background humidity
- Fingerprints for the array are generated at different temperatures and background humidity
- Parameters for the identification and quantification software are generated from these data

ID and Quantification of Single Analytes



Response of Sensor Arrays to Acetone



False Positives (identification of unknown event at times where there was no event) are deleted.

ENose on ISS - Overview

- EXPRESS Rack Payload, six month experiment, on ISS
- Designed, fabricated, and operated as part of a cooperative agreement between NASA's Exploration Systems Mission Directorate (ESMD) and Space Operations Mission Directorate (SOMD) (Flight sponsored by ISS Vehicle Office/ NASA JSC- OB)
- Designed and built by the Jet Propulsion Laboratory (JPL)
- Targeting Shuttle launch ULF 2 (Sept '08, Increment 18) or 15A (November '08, Increment 18); 6 months continuous operation on ISS
- Baseline Installation Configuration on ISS: EXPRESS Rack, 28 Vdc
- Backup Installation Power Configuration: Black Brick (16Vdc) from 120Vdc Utility Outlet Panel (UOP)

Deployment Options

<---- Velcro Mounted

Seat Track Mounted ---->

Summary

- **ENoses can be used to identify and differentiate complex mixtures and individual chemicals**
- **An ENose will satisfy NASA Air Quality *Event Monitoring* Requirements**
- **JPL's Generation 3 ENose is under development as a Technology Demonstration Event Monitor on ISS.**
- **ISS Tech Demo analyte set includes volatile organics and Hg and SO_2**
- **Generation 3 ENose will include on-board computing and real-time data analysis**

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