Noninvasive Breath Analysis Using NASA E-Nose Technology For Health Assessment

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ABSTRACT

Clinical breath analysis is based on the fact that many important metabolites and biomarker molecules are present at detectable levels in exhaled breath, and many of these molecules correlate with human disease or correlate with physiological states that could lead to a decline in health.
Presented is a technology that utilizes an array of chemical sensors combined with humidity, temperature and pressure for real time breath analysis to correlate the chemical information in the breath with the state and functioning of different human organs. For example, a marker for pulmonary inflammation processes of the lower respiratory tract, e.g. asthma, is the increase of the nitrogen oxide (NO) concentration in breath. Other volatile biomarkers may correlate with infectious process, metabolic conditions and inflammatory diseases, such as traumatic brain injury (TBI). This technology is also called "electronic nose" (E-Nose) in the sense that the device can mimic human nose to smell odors using a pattern recognition technique to analyze the sensor array data.
Breath sampling is non-invasive and can be analyzed in real-time.

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INTRODUCTION

A number of volatile compounds, so called "biomarkers", were found in breath samples, normally at low ppb-levels and the background relative humidity is high, almost 100%. This condition requires an analytical tool with very high sensitivity for its measurement. Our technology [1,2] can provide a high sensitive, low power and compact tool – the NASA E-Nose, for such an analysis in-situ and in real time. This tool can provide a non-invasive method for fast and accurate diagnosis at the medical care of point or at home. This sensor chip have multiple sensors on it for a comprehensive measurement of chemical composition, temperature, humidity, and pressure. The sensor data collected from this chip can be wired or wirelessly transmitted to a computer terminal at the doctor's desk or hospital monitoring center. The sensor chip can be connected directly or via USB or Bluetooth to a smartphone for data transmission over a long distance and receive an instruction from a doctor's office for the immediate therapy. This technology changes the way and time decisions are made to help both patient and medical care provider to minimize their cost, optimize resources, reduce risk and cut the amount of time needed for conducting response. The NASA E-Nose technology can provide a solution to the above application.
The technology is originally designed for space medicine, but it can be used for civilian medical diagnosis [3,4] and military medical diagnostics/monitoring as well, such as for *prolonged field care and en route care.*

METHODS AND MATERIALS

We use different carbon nanotubes (CNTs) with pairs of gold electrodes laid on top of silicon wafer with silicon dioxide as an insulator. The resistance of the CNTs are measured before and during the gas molecules adsorbed to the surface of CNTs. The change of the resistance correlates to the concentration of the gas molecules and specific type of CNTs will be selective to certain type of gas molecules. The working principle of the sensor and the sensor array is depicted in the Fig. 1 below.

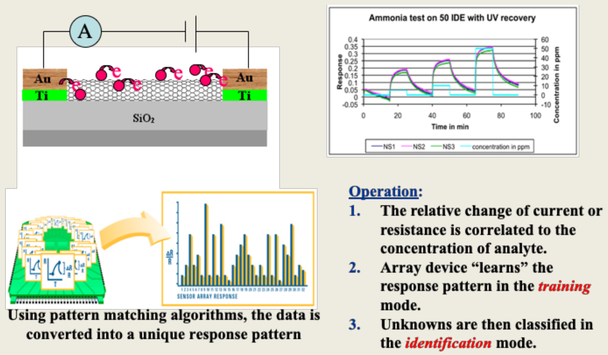


Figure 1. Working principle of a carbon nanotube sensor and the sensor array

RESULTS

Our sensors have the following capabilities:
- Many analytes have been measured (Table 1) with detection limit range: ppm to ppb (e.g. recently, our sensor can detect 10ppb NO)
- Fast response time in seconds at room temperature
- Highly reproducible from sensor to sensor
- Low power: μW to mW/sensor
- Easy integration (2-terminal I/V measurement)
- Small sensor chip sized in 1x1cm^2 with 12-96 channels

Breath analysis is an emerging technology that shows great promise for medical diagnostics and health monitoring in a wide range of settings, and is particularly attractive for health assessment of soldiers in battle field and crew members on deep space missions.

Table 1. A list of chemicals that have been tested with our CNT sensors.

Analyte	Sensitivity/Detection limit
CH_4	1ppm in air
Hydrazine	10ppb tested by **KSC**
NO_2	4.6ppb in air
NH_3	0.5ppm in air
SO_2	25ppm in air
HCl	5ppm in air
Formaldehyde	10ppb in air tested by **JPL**
Acetone	10ppm in air
Benzene	20ppm in air
Cl_2	10ppm in N2
HCN	10ppm in N2
Malathion	open bottle in air
Diazinon	open bottle in air
Toluene	1ppm in air
Nitrotoluene	256ppb in N2
H_2O_2	3.7ppm in air

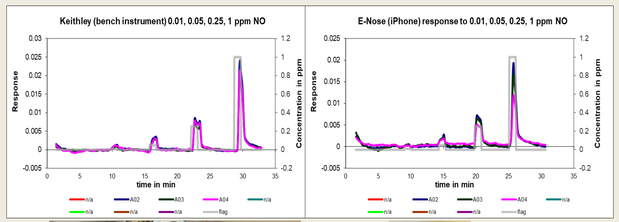
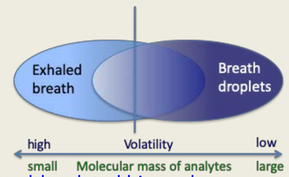


Figure 2. Comparison of test results obtained by a desktop instrument (left) and the E-Nose (right)

DISCUSSION

The "richness" of exhaled breath as a diagnostic bodily fluid is based on the fact that breath contains a variety of both volatile biomolecules and non-volatile molecules, such as small organic molecules, peptides and even larger macromolecules that are entrained in the stream of exhaled breath. We use a sensor array to form an electronic nose to mimic human nose:
1) it can detect these biomarkers and give an early warning,
2) the measurement result can be sent to the doctor right away with location and environmental information for helping the judgment of the real situation.
3) It is small, light weight and low power for carryon or stationary use at home and point of care facilities or on the road.

Exhaled breath is a window into your health



Exhaled breath contains many health-related biomarkers.
- Small molecules (e.g., NO)
- Volatile organic compounds = VOCs (acetone, alkanes, …)
- Larger, non-volatile molecules (e.g., proteins) contained in aerosol droplets

Breath sampling is non-invasive and can be analyzed in real-time.

Summary

- Started the development work at NASA Ames since 2002
- Highly matured and most well-developed Nano Chemical Sensor System in the world to date
  - Tested aboard a US Navy Satellite in 2007 for 12 months
  - Deployed in JPL E-Nose on the International Space Station (Cabin air quality monitor) since November 2008 for 6 months
  - Arranged by Dept. of Homeland Security for field-test of various threats and conducted a cross country demo
- 35 peer-reviewed journal publications
- 9 US patents

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