Mid-IR spectroscopy for flame and surface characterization

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Outline

- Company and product overview
- Fundamentals of Mid-IR Spectroscopy
- Practical examples
Company and Products Overview

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Mission, Vision and Values

En'Urga's vision is to apply research findings in basic science and engineering towards the development of innovative products and processes that harmonizes the human spirit and technology.

Our mission is “To become the leader in Industrial Process Tomography systems throughout the world”

En'Urga strives to provide exceptional service with the state of the art technology to meet our customer’s objectives.
SETscan Optical Patternator

US Patent number 6,184,989

- Used for testing automotive and aeroengine injectors, as well as coating, paint, and consumer nozzles
- Customized database including CFR Part 11 compliance for Pharmaceutical Industry
- Sample customers: Abbot, Delphi, GE, GM, Honeywell, Eaton, Rolls Royce, Tenneco, United Technology, Pfizer
Spectraline Hyperspectral Imager

- Used for monitoring high temperature events
- Database include determination of temperature, emissivity, and gas concentrations
- Representative customers: Siemens, Dow Corning, Poohang Steel, Jupiter Aluminum, and FM

US Patent number 6,355,930
Spectraline Infrared Line Imagers

- Used for monitoring hot ignots, plastic webs, and surface coating on sheets
- Database include determination of temperature, emissivity, cracks, and defects
- Representative customers: Poohang Steel, 3M, Hevea Engineering, and Hyundai Automotive

US Patent number 6,355,930
SCIvel velocimeter

- Used for measuring velocities in fires, sprays, belts, and two phase flows
- Fully customized for multiple applications
- **Representative customers:** 3M, Air Force, Dow Corning, and NASA

US Patent number 8,134,703

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X-Ray Inspection Systems

US Patent number: Application on file

- New product introduced in FY2014
- Industrial measurement of powder flow, optical dense sprays, product defects, and two phase flows
- Configured to meet customer quality audit needs
- Representative customers: Virginia Tech., Purdue University, Ekamber, Air Force
Mid-IR Spectroscopy
Hardware

- Co-registry of all wavelengths
- High speed to eliminate turbulence/radiation fluctuations

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Line of Sight Measurements

- Path integrated measurement of radiation intensity
- Converted to temperature, gas concentrations using models
Radiation Models

- Assume homogeneous or parabolic profiles of T and CO₂
- Forward calculation using either RADCAL and HITRAN narrow band models
- Using difference between calculations and input values to update values and recalculate
- Convergence is typically in less than 1 second per point
Fan Beam Arrangement

Emission tomography with high spatial resolution
Used for non-homogeneous paths
Detailed profile-not an online monitoring tool
Emission Tomography

• **DECONVOLUTION PROCEDURE:**
  • Step 1: Measure path integrated spectra
  • Step 2: Deconvolute for the local emission spectra (neglecting self absorption)
  • Step 3: Calculate temperatures and local properties from spectra.
  • Step 4: With known local properties estimate absorption field and perform deconvolution with absorption.
  • Step 5: Iteratively (~ 5 to 6 loops) obtain local properties and absorption till converge is obtained.
Practical Examples
Measured Intensities

Siemens Westinghouse Power Corporation
Natural Gas Combustor, P = 6.2 bar
Estimated Temperatures

![Graph showing the relationship between temperature, power level, and NOx levels.]

- **Data**
  - IR Sensor, K
  - Thermocouple, K
  - NOx, ppm

**Temperature (K)**

- 50
- 60
- 70
- 80
- 90
- 100
- 1200
- 1400
- 1600
- 1800

**Power Level (%)**

- 50
- 60
- 70
- 80
- 90
- 100

**NOx (ppm-wet)**

- 100
- 110
- 120
- 130
- 140
- 150
- 160
- 170

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Gas Concentrations

![CO₂ and H₂O concentration graph]

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Measured Intensity

General Electric Corporation (CRD)
Kerosene Spray Flame

\begin{center}
\begin{tabular}{|c|c|c|}
\hline
$\phi$ & IR sensor & Inverse \\
0.551 & - & - \\
0.593 & - & - \\
0.518 & - & - \\
\hline
\end{tabular}
\end{center}

\begin{center}
\begin{tikzpicture}
\begin{axis}[
    xlabel={Wavelength (\textmu m)},
    ylabel={Radiation Intensity (W/m$^2$/str/$\textmu$m)},
    xmin=2, xmax=5,
    ymin=0, ymax=8000,
    xtick={2,2.5,3,3.5,4,4.5,5},
    ytick={0,2000,4000,6000,8000},
    legend entries={{IR sensor}, Inverse}
]
\addplot+[mark=*,mark options={red}, line width=1pt] table [x=\textmu m, y=IR_sensor] {data.txt};
\addplot+[mark=square*, mark options={black}, line width=1pt] table [x=\textmu m, y=Inverse] {data.txt};
\end{axis}
\end{tikzpicture}
\end{center}
Estimated Temperature

Graph showing the relationship between temperature (K) and equivalence ratio ($\phi$) for IR Sensor and Adiabatic conditions.
Measured Intensity

Rolls Royce Bio-fuel Combustor

**Spectral Intensity (kW/m²/sr/µm)**

**Wavelength (mm)**

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Estimated Temperatures

![Graph showing estimated temperatures for bio fuel and soot band only across various test points.](image)
Turbine Blade Monitoring

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Blade Temperature

Scan Number

Blade Temperature (K)
Monopropellant Flames

Jet Propulsion Laboratory/Sandia National Laboratory

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Estimated Temperature Profile

- Estimated Temperature Profile diagram showing gas temperature (K) versus distance (mm) for different distances and models.

- Key points:
  - Gas Temperature (K) range: 500 to 4000 K
  - Distance (mm) range: -300 to 300 mm
  - Models: 20 inch, M #1, 12 inch, M #2, 6 inch, M #3

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