High-Speed Identification of Trace Chemicals on Conveyor-Driven Parcels

Derek Wood, Alyssa Montalbano, Leyun Zhu,
Wynn Bowers, Dimitry Maltsev, and Anish Goyal

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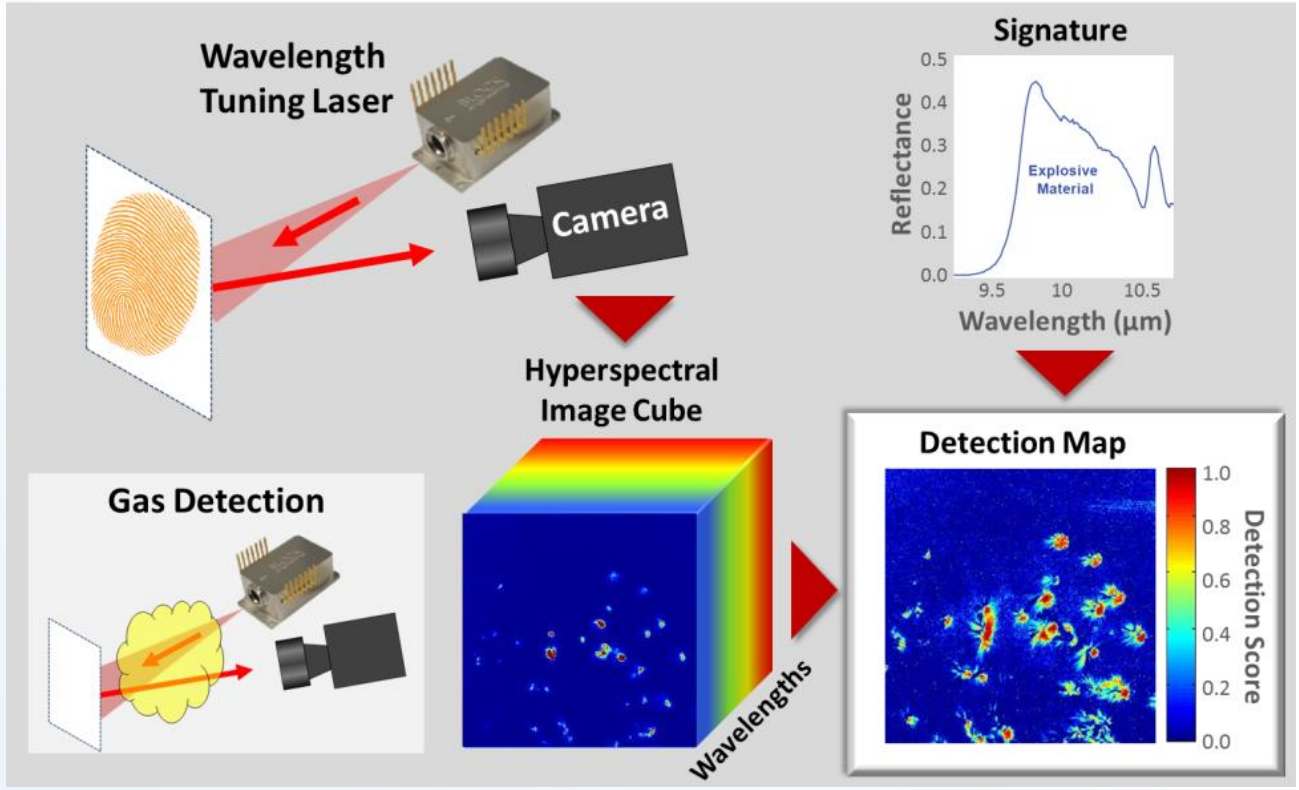
Laser-Based, Long-Wave Infrared (LWIR) Hyperspectral Imaging (HSI)

- Powerful method for detecting, identifying, and mapping trace chemicals on surfaces
  - Most chemicals have strong and unique absorption spectra in the LWIR
  - High sensitivity & specificity, eye-safe
- Measure the spectral reflectance from a surface using an EC-QCL + Camera



See: Goyal, et al., SPIE Optical Engineering, Special Issue on Active Spectroscopy (2020)

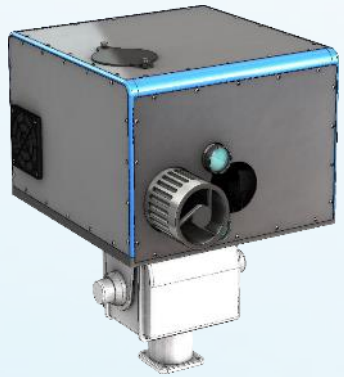
Trace Chemical Detector (TCD) Applications

- Most of the core technology is common for all variants
  - lasers, electronics, software, algorithms
- Camera is most important differentiator (performance vs cost)

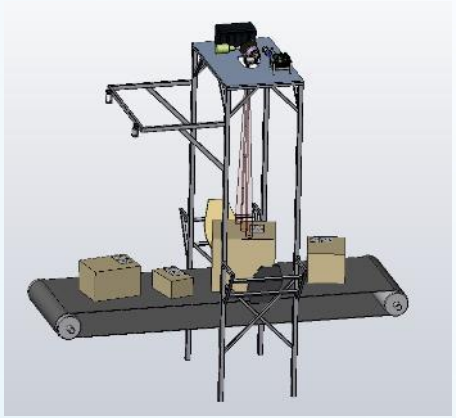
High-Performance
(MCT Camera)

Low-Cost
(Microbolometer Camera)

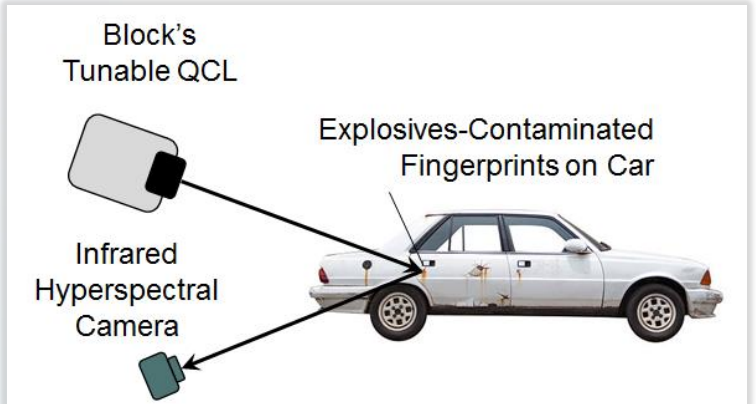
Long-Range Standoff



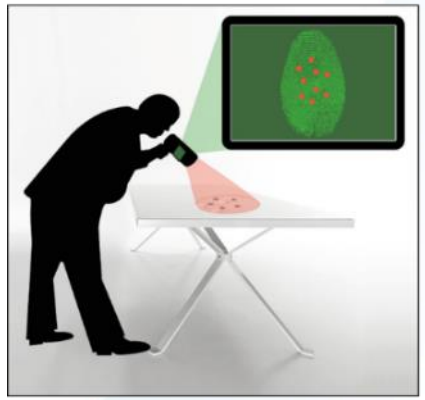
Parcels on Conveyor Belt



Vehicle Checkpoint



First Responders / Site Assessment



Trace Chemical Detector for Parcel Scanning

- Prototype Trace Chemical Detector (TCD) was developed under the IARPA SILMARILS program
- MCT camera operated in windowed mode for high speed
  - 6,400 fps with window of 32 x 128 pixel
  - Imaged area of 13 x 52 mm
- Motorized camera lens with fast focus of < 100 ms
- Laser source combines the light from 3 EC-QCLs

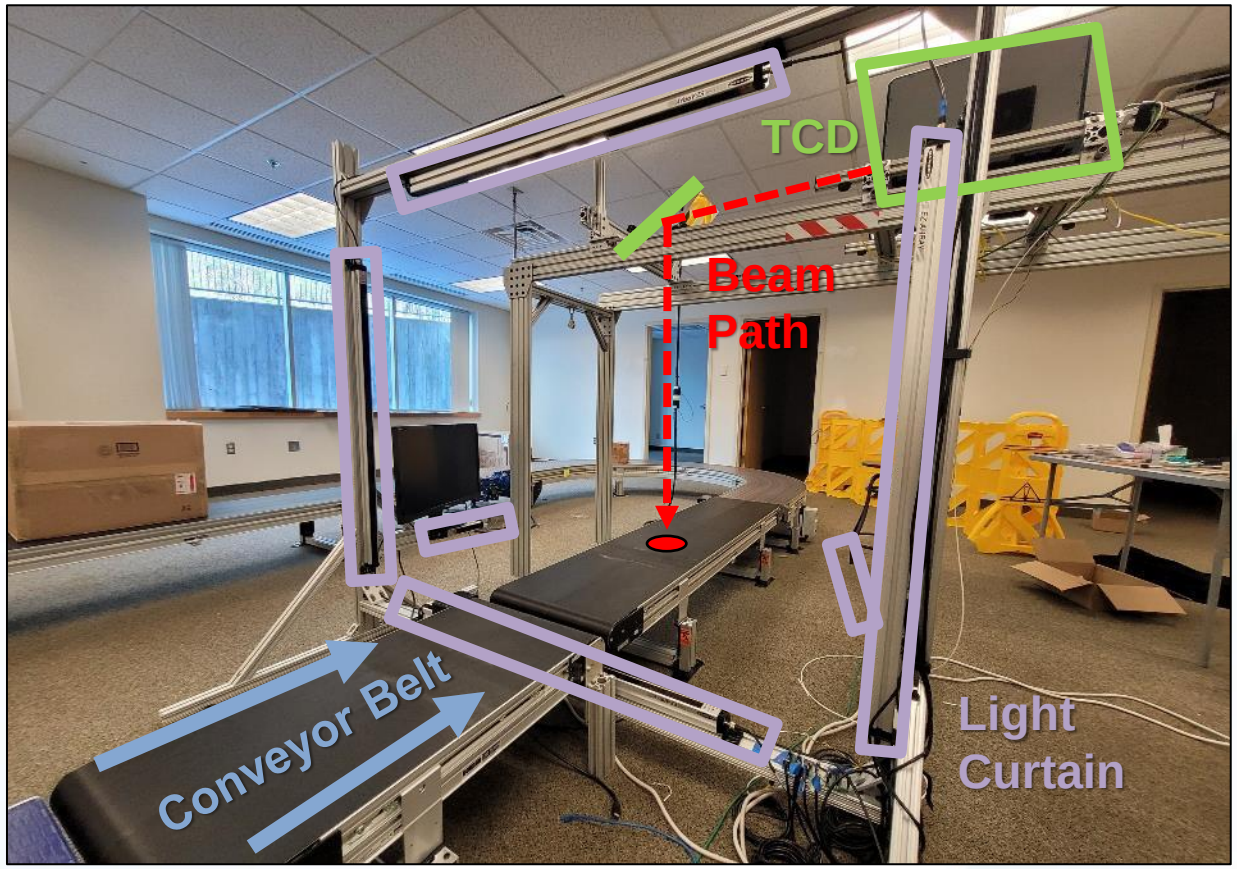
Camera type	Liquid-nitrogen cooled MCT
Camera frame rate	1,600 fps (128 x 128 pixels) 6,400 fps (32 x 128 pixels)
Standoff distance	1.5 – 2.5 m, motorized
Spatial resolution @ 2 m	0.4 mm / pixel
Wavelength range	7.3 – 11.2 µm
Laser power	~25 mW average power

SILMARILS Prototype Trace Chemical Detector

Parcel Scanner Prototype

- Automatically measures, detects, and reports contamination on parcels moving at speeds up to 400 ft/min (2 m/s)
- A light curtain measures the height, length, and speed of parcels
  - From thin envelopes to parcels as tall as 1 meter
- Acquisition
  - Automatically starts and ends acquisition based on measured length and speed
  - Camera focus based on package height
  - Laser centered on camera FOV based on height

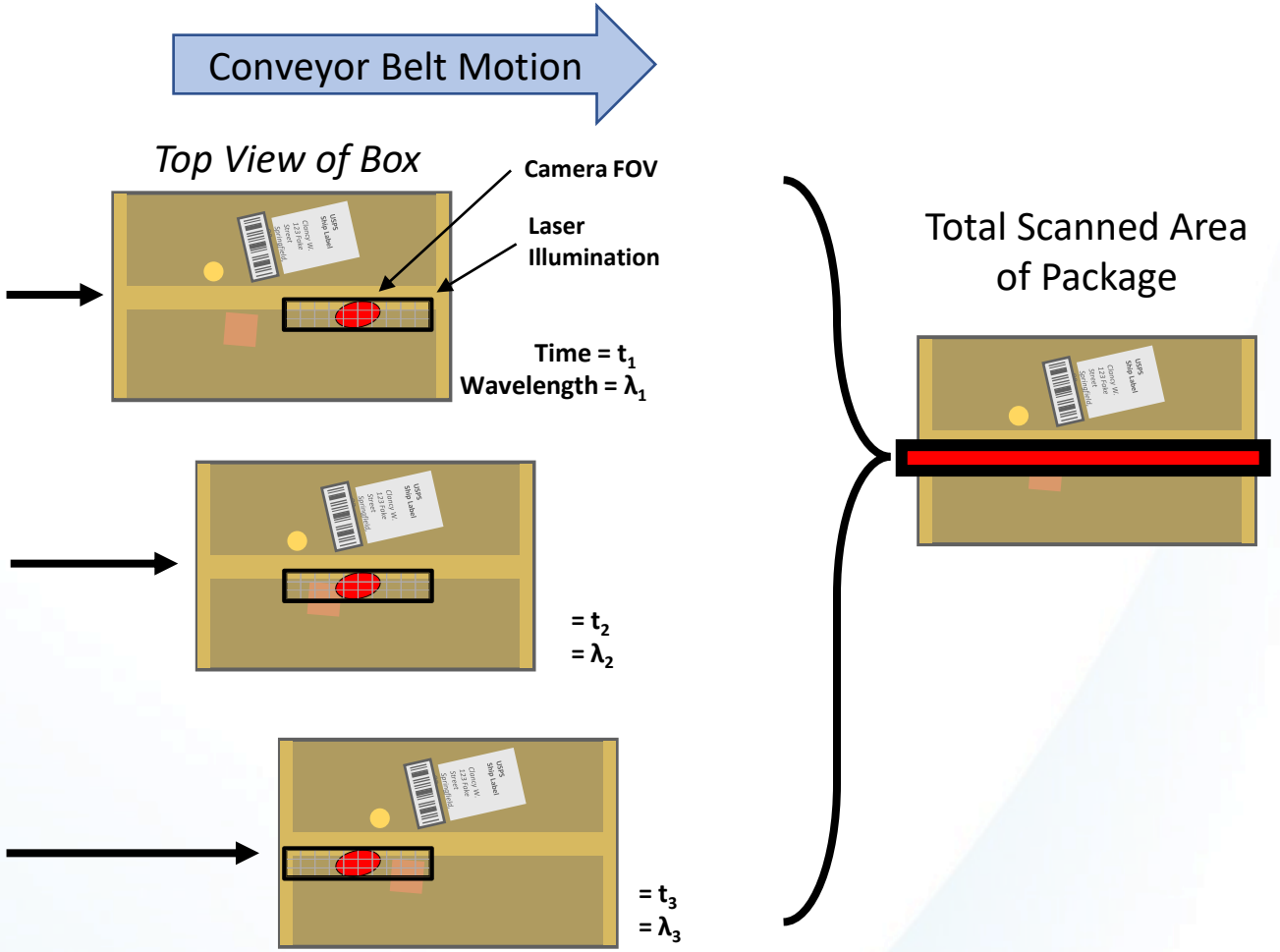
Photograph of Testing Setup



Principle of Data Acquisition

- Continuously measure a stationary 13mm (0.5”) circular spot while the parcel is conveyed
  - Wavelength is tuned from 7.3 – 11.2 μm
  - Full sweep in less time than move one beam size
  - Hypercube stripe across top surface of entire parcel
- Result is a 32 x N pixel hypercube
  - Typical 40cm box → N = 1000 pixels
  - Demonstrated acquisition up to 400 ft/min
- Most of the data was measured at 50 ft/min

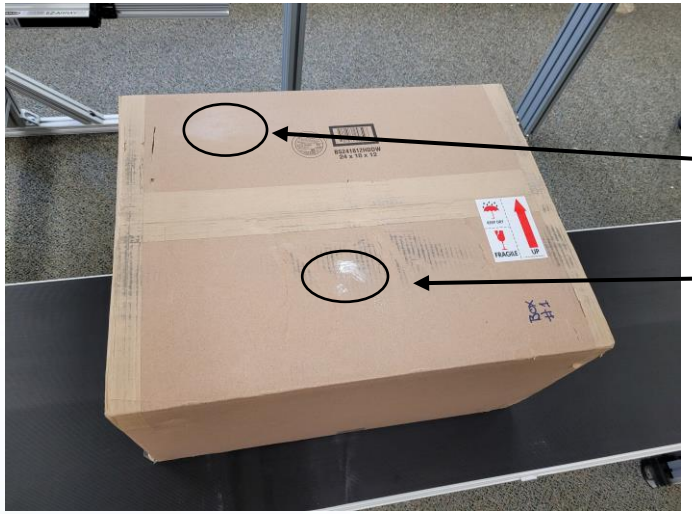
Speed		Spectral	Spectral Resolution	
m/s	[ft/min]	Channels	[μm]	[cm-1]
0	0	306	0.01	1.3
0.4	80	161	0.02	2.7
0.8	160	91	0.04	4.9
2	400	48	0.08	9.2



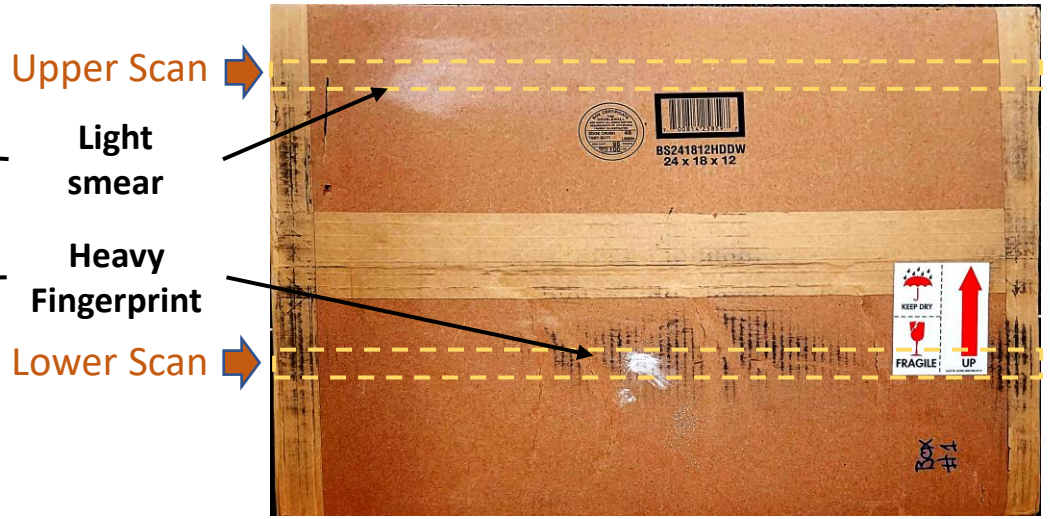
Pentaerythritol on Cardboard Box

- Contamination in 2 locations
  - Heavy fingerprint
  - Light smear
- Moving at 50 ft/min
- Scanned area of 1.3 x 66 cm
  - 32 x 1650 pixels

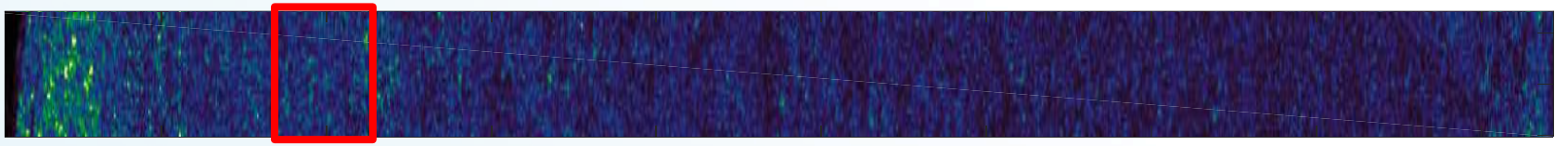
Box on Conveyor



Contrast-Enhanced Image of Box

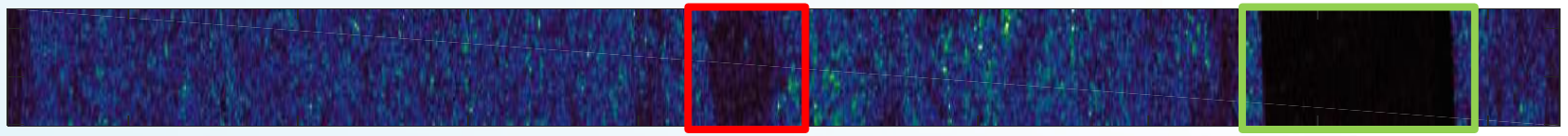


Hyperspectral Images (not to scale / avg over wavelengths)



Contamination

Upper Scan



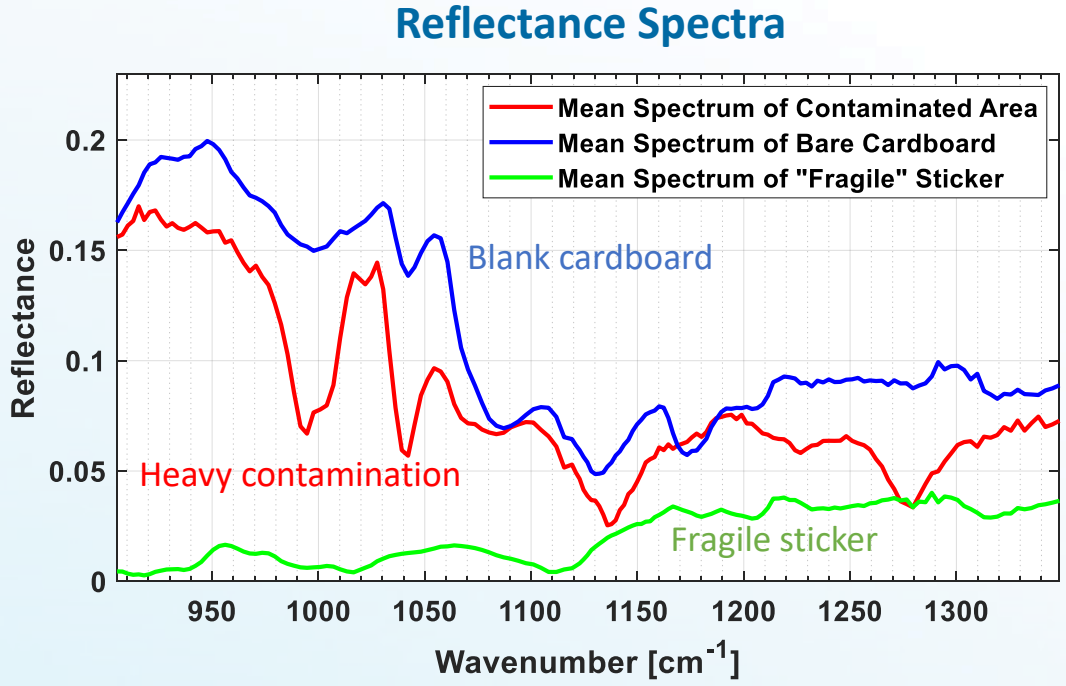
Contamination

"Fragile" Sticker

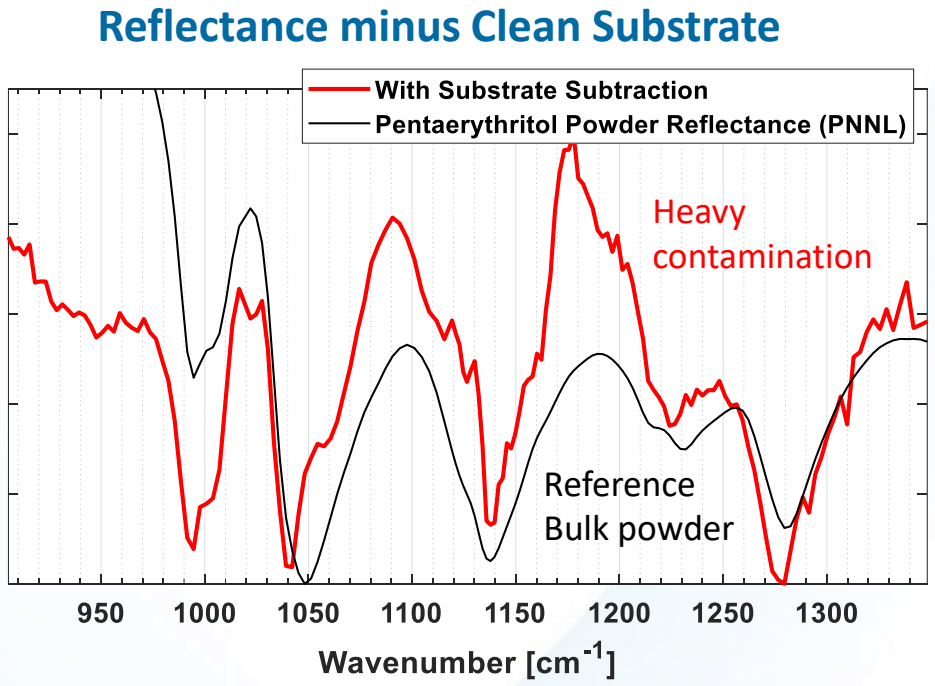
Lower Scan

Heavy Fingerprint of Contaminant

- Compare the reflectance in the various regions
- Subtract substrate reflectance from that in the heavily contaminated region
  - Reasonably good correspondence with reflectance from bulk powder
- Pentaerythritol is readily identified

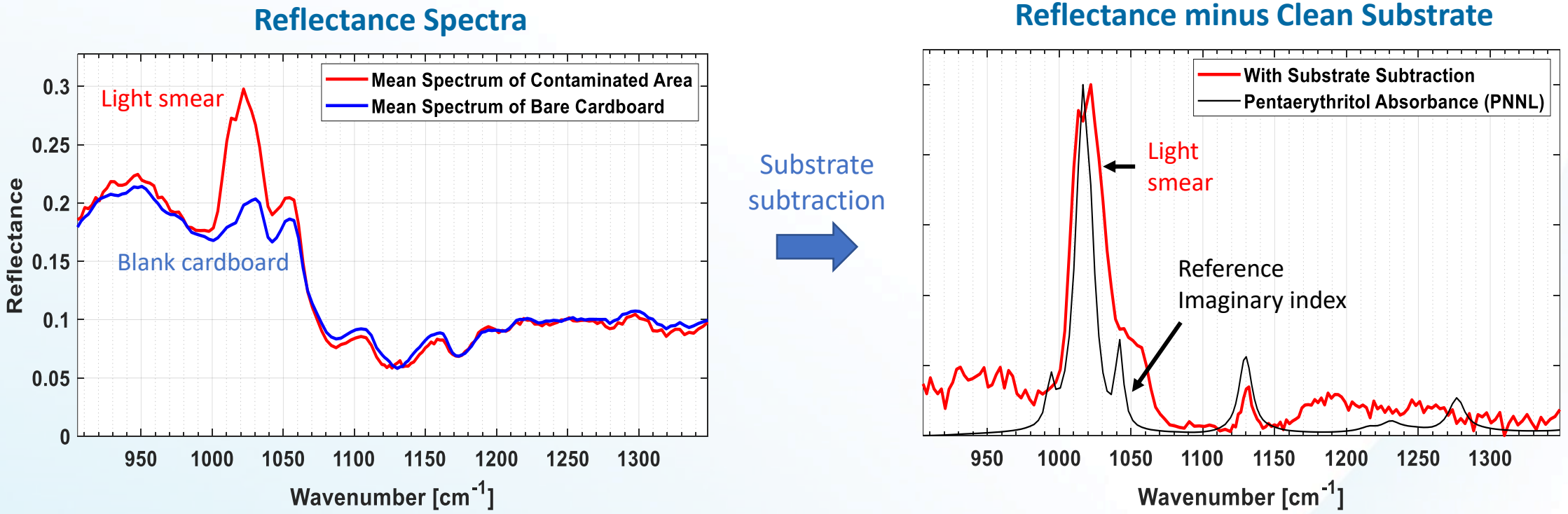


Substrate subtraction



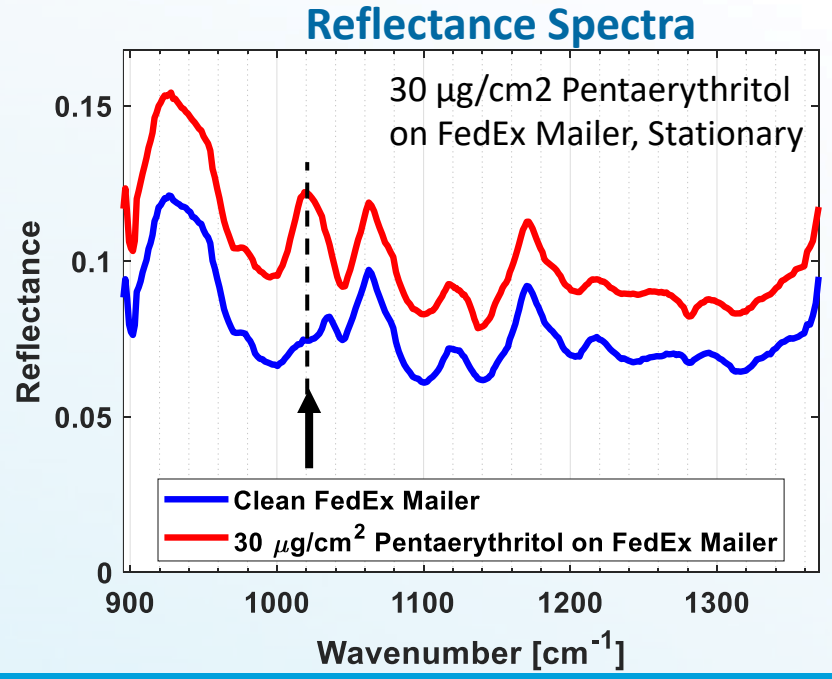
Light Smear of Contaminant

- Clear signature observed even for a light smear
- After substrate subtraction, chemical signature is clearly observed
  - Correlates with absorbance (imaginary index) of pentaerythritol
  - Signature as expected for a thin film on a dielectric substrate

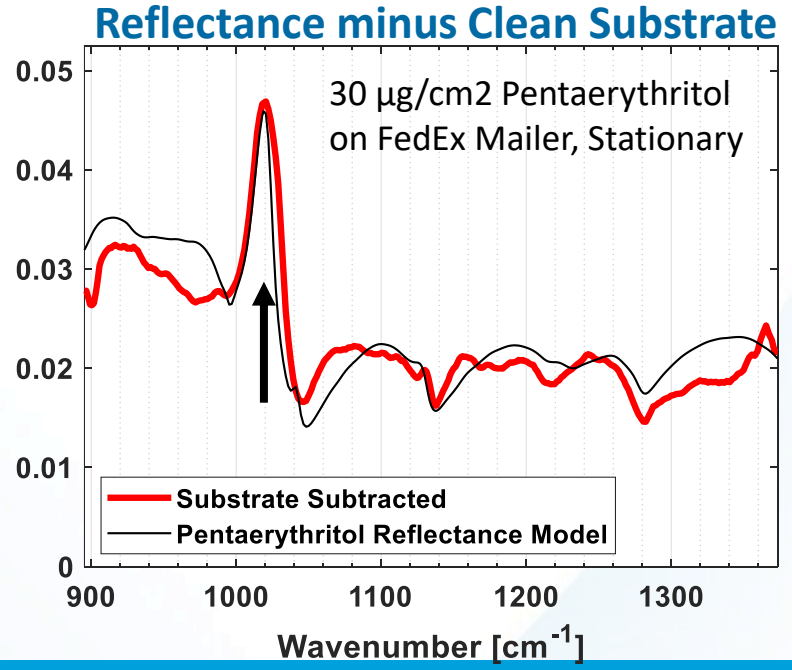


Limits of Detection (LODs)

- An extensive testing campaign was performed to determine the LODs
  - Multiple types of packaging surfaces, contaminants, and deposition methods
  - LODs depend on all of these factors
  - Shape of the spectra depends on deposition method
- In general, trace contamination was detected at concentrations of ~100 µg/cm^2
  - Able to measure as low as 10 µg/cm^2 for specific contaminant/substrate combinations
  - Example of 30 µg/cm^2 solvent deposition on FedEx Mailer; intermediate signature

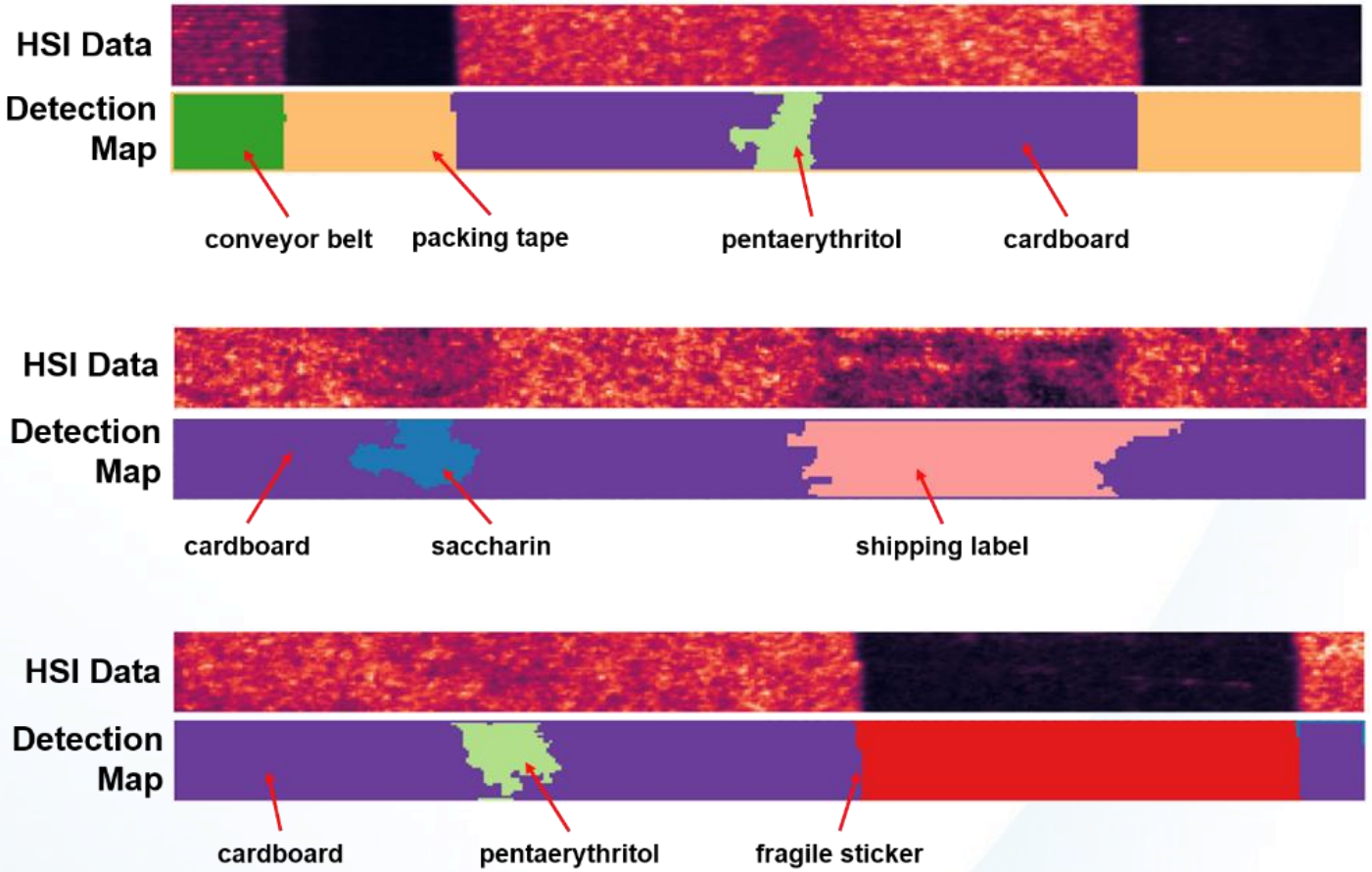


Substrate subtraction



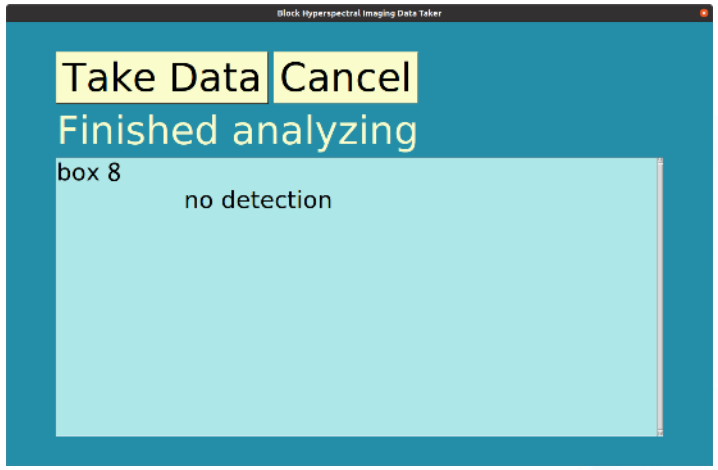
Automation: Image Segmentation & Detection

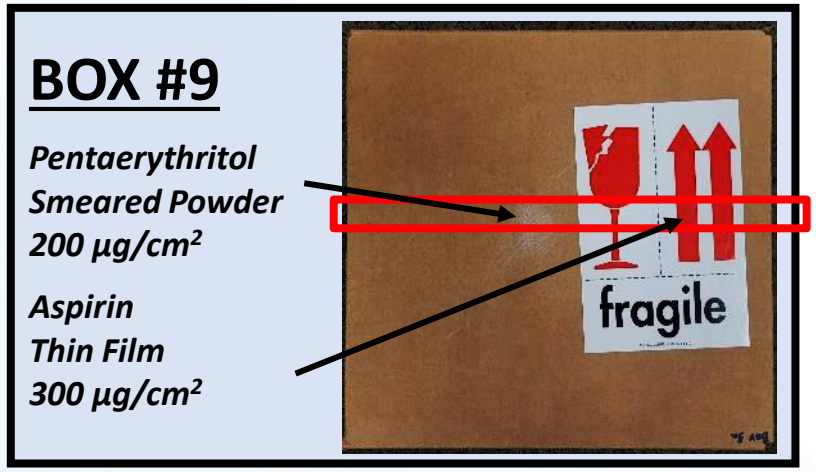
- Developed automated segmentation algorithm
  - Distinguish and identify many common parcel materials
  - Extract “clean” local substrate reflectance to optimally subtract background spectrum
- The segmentation algorithm is robust for this parcel screening application
- Detection algorithm applied to each segment

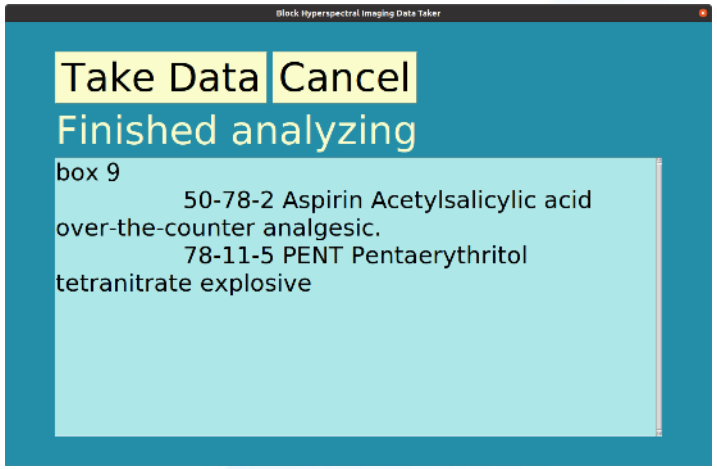


Automation: Continuous End-to-End Detection

- System has a simple user interface
- Operation of system is continuous and fully automatic
  - Arm system
  - Acquire measurement
  - Automatically process data
  - Display detection results
  - Save data
- Good results on actual parcels with complex surfaces
  - Stickers, labels, tape, etc.







Summary & Conclusion

- Successfully demonstrated the detection of trace chemicals on parcels while moving on a conveyor belt
- System can accommodate speeds up to 400 ft/minute (2 m/s)
- Detect contaminants on a wide variety of parcel surfaces
- Typical LODs of ~100 µg/cm^2, reaching as low as 10 µg/cm^2 depending on surface and contaminant chemistry
- Automated interface provides continuous monitoring of conveyed goods

Acknowledgements: We thank DHS for their support of this project.