ROYAL MILITARY ACADEMY
SKRALAN HOSTEAUX

6 November 2024

DEFENCE

Military applications of hyperspectral imaging

Hyperspectral research unit

RMA Brussels
Royal Military Academy

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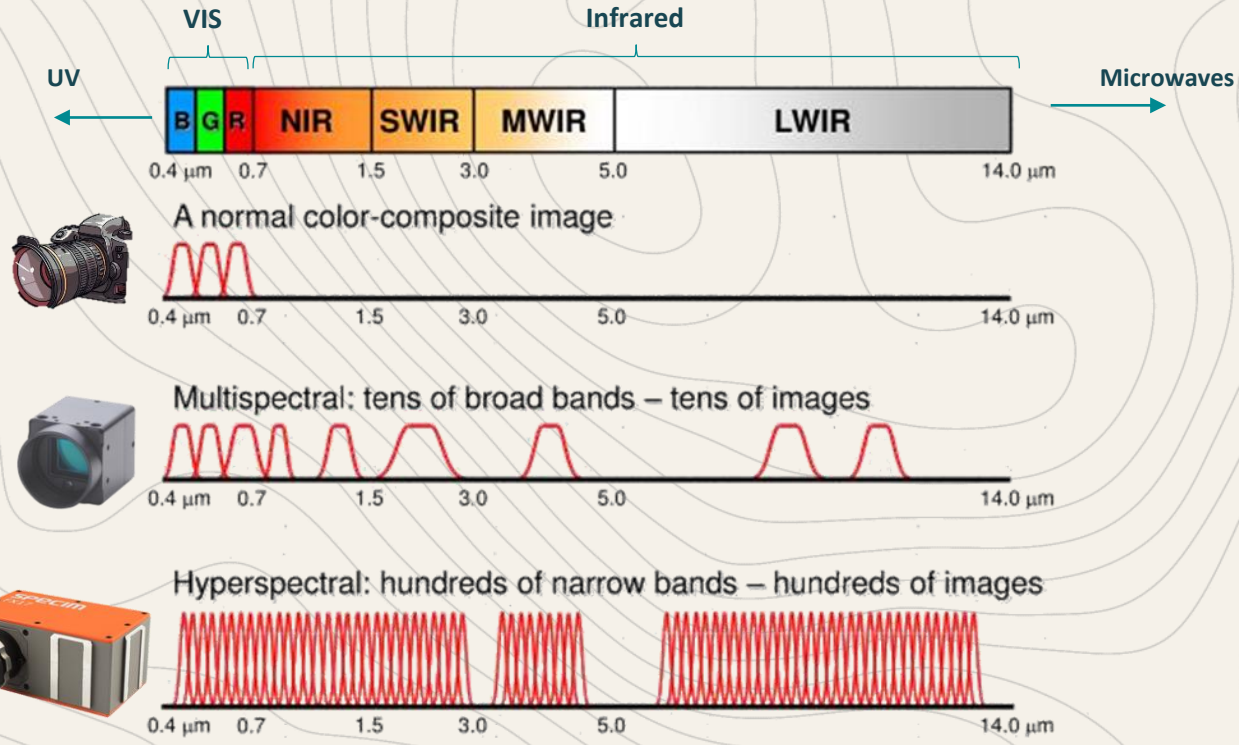
HSI principles in a nutshell

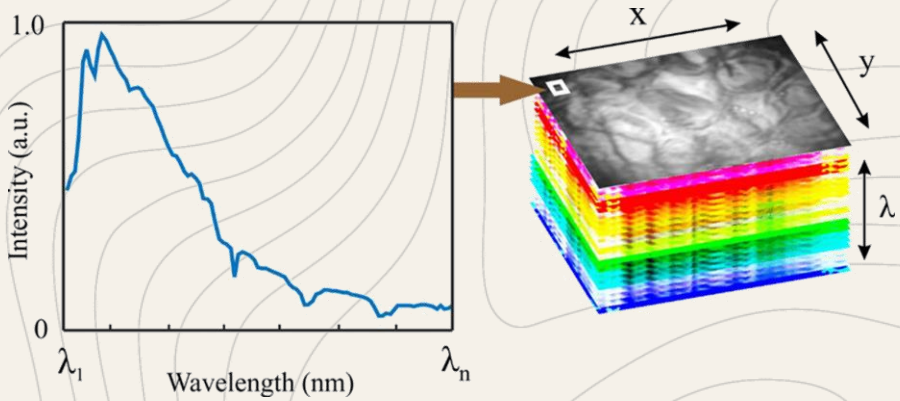


R. Resmini: Hyperspectral Remote Sensing Workshop ASPRS/Potomac Region's GeoTech 2013

Main HSI parameters:

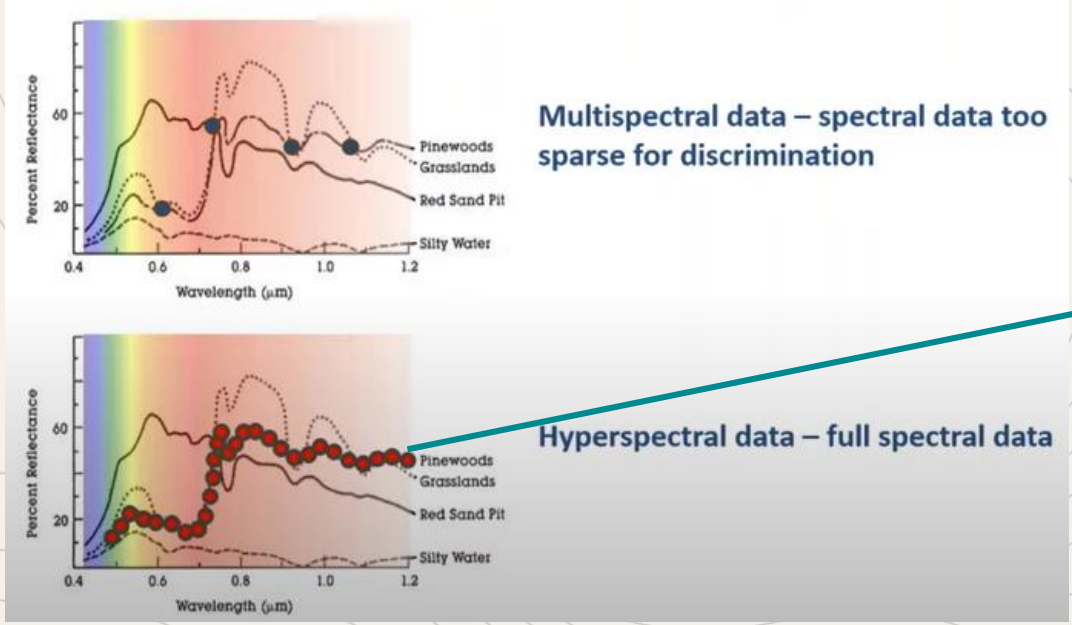
- Number of spectral bands
- Width of each band
- Continuity of bands

Data cube

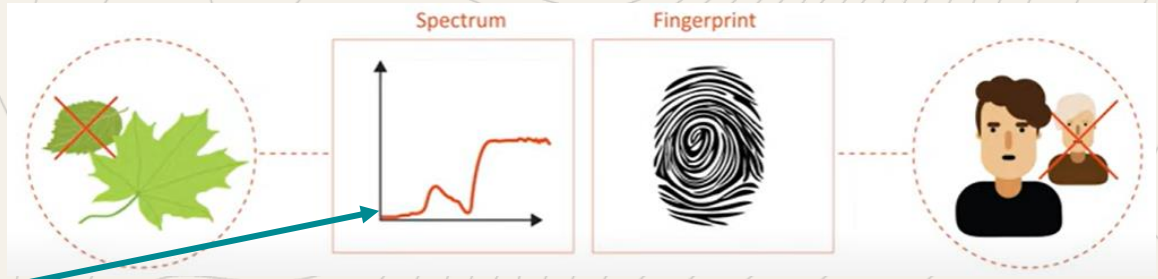


Zalavadia, Ajay. (2018). A Broadly Tunable Surface Plasmon-Coupled Wavelength Filter for Visible and Near Infrared Hyperspectral Imaging.

HSI principles in a nutshell



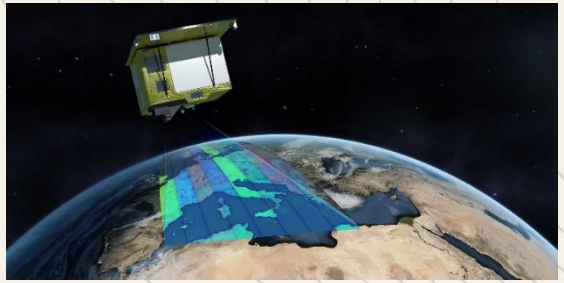
Encyclopedia of Agrophysics, Gliński, Jan et. Al 2011



Specim: Hyperspectral imaging tutorial

HSI principles in a nutshell

Space-based

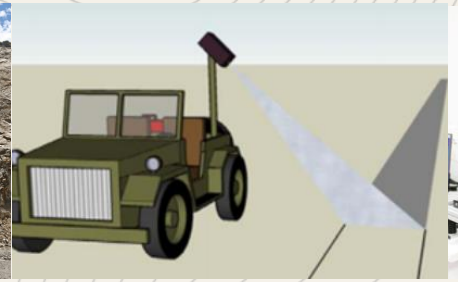


Source: EnMap

Airborne

Source: Resonon Hyperspectral Airborne Remote Sensing Systems

Ground-based



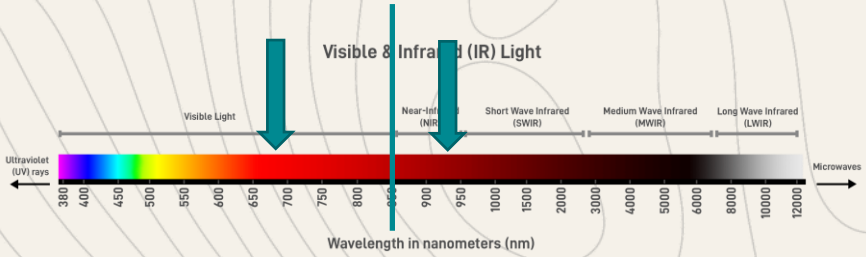
Source: Hyspex hyperspectral imaging

Applications:

- Agriculture (plants in need of water, ….)
- Food inspection (rot, ….)
- Environmental studies (pollution, methane leak detection….)
- Geology (minerals, ….)
- Health (blood oxygenation, ….)
- Military (camouflage/mine detection, …)
- …

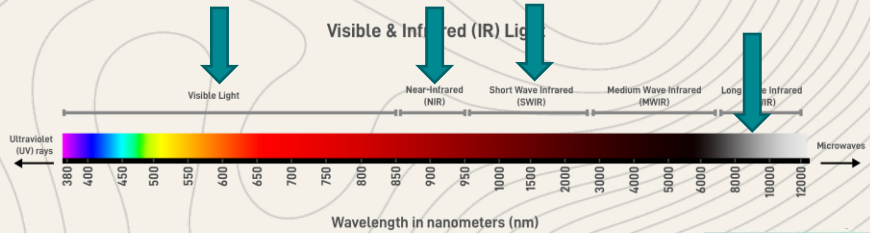
HSI applications for defence

- Detection and tracking of personnel under hindered light conditions

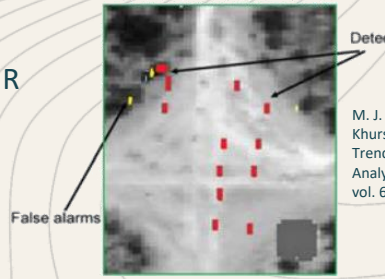


L. Antson et al, "Detection and Tracking of Search and Rescue Personnel Under Hindered Light Conditions Using Hyperspectral Imaging," 2022 12th Workshop on Hyperspectral Imaging and Signal Processing: Evolution in Remote Sensing (WHISPERS), Rome, Italy, 2022

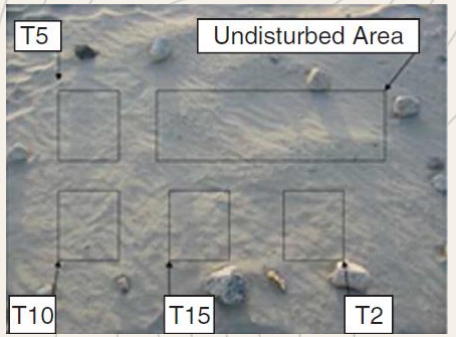
- Detection of (buried) explosives

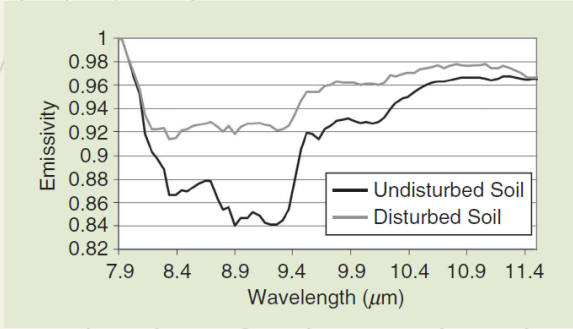


- Surface-laid well detectable in VIS-SWIR
- Disturbed soil has different spectral properties (aka Reststrahlen effect)



M. J. Khan, H. S. Khan, A. Yousaf, K. Khurshid and A. Abbas, "Modern Trends in Hyperspectral Image Analysis: A Review," in IEEE Access, vol. 6, pp. 14118-14129, 2018,





J. M. Cathcart et al: "Impact of soil and environmental processes on hyperspectral infrared signatures," in *Proc. SPIE 5415*, 2004.

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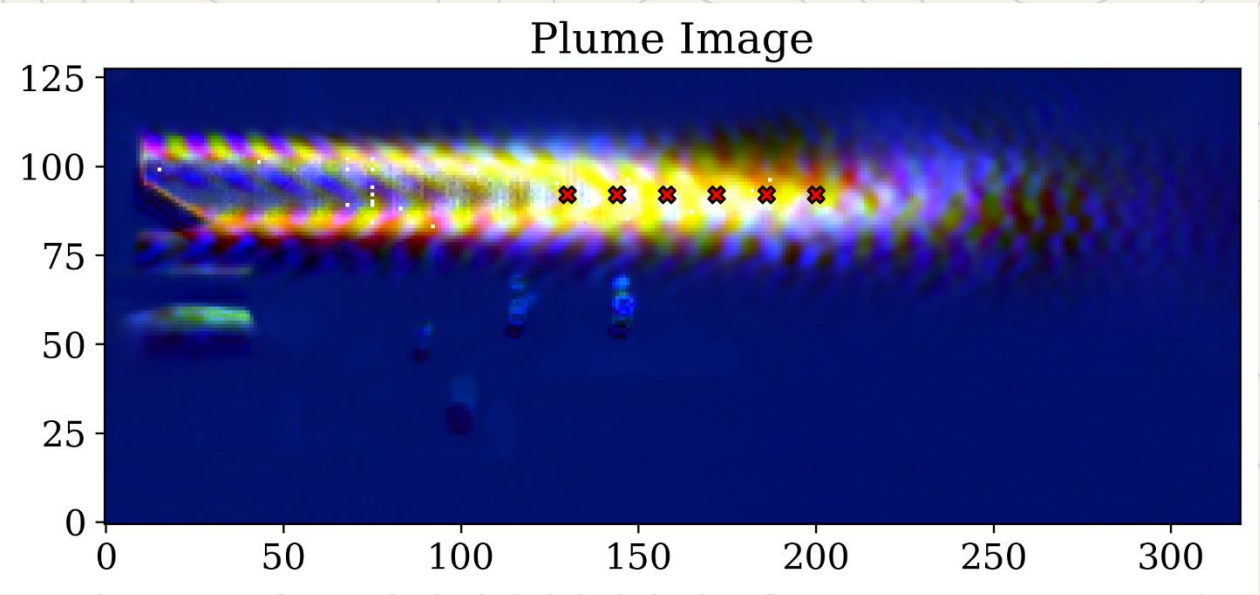
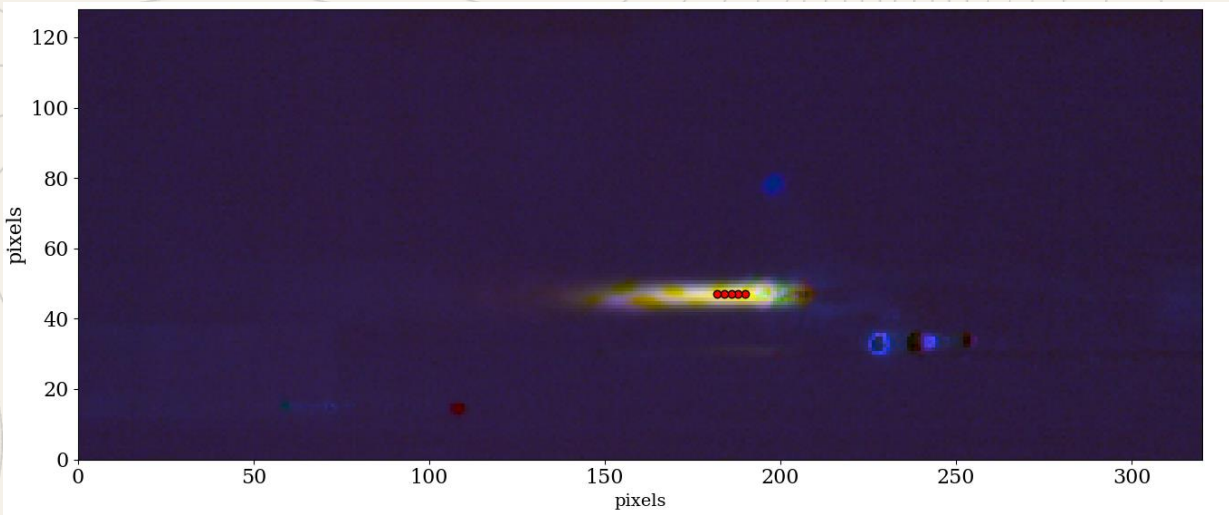
Use case: Jet Engine Monitoring



Moving plume run



Spectral signatures are:

- Constant over t
- Constant over s

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Spectral
Spectral
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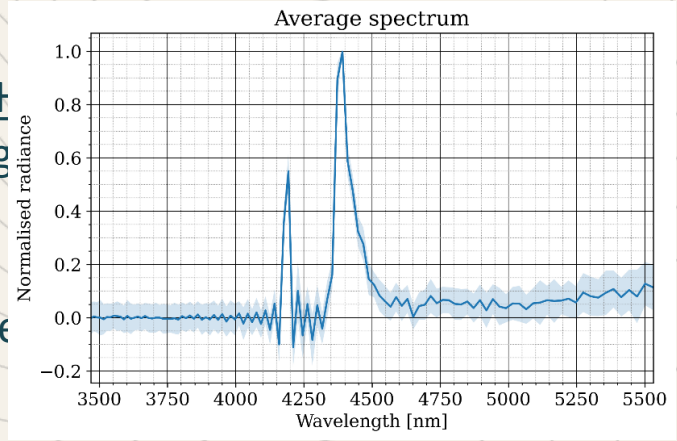

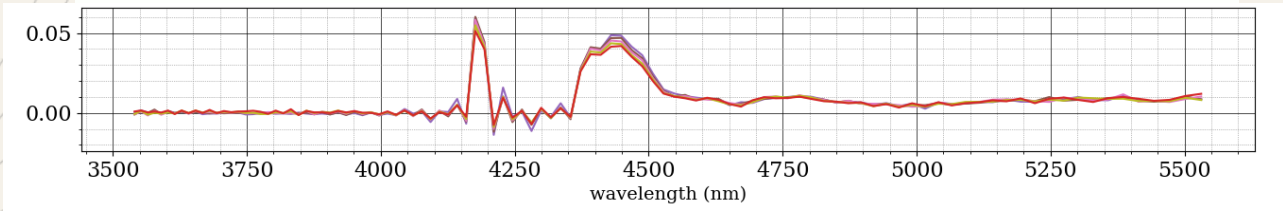

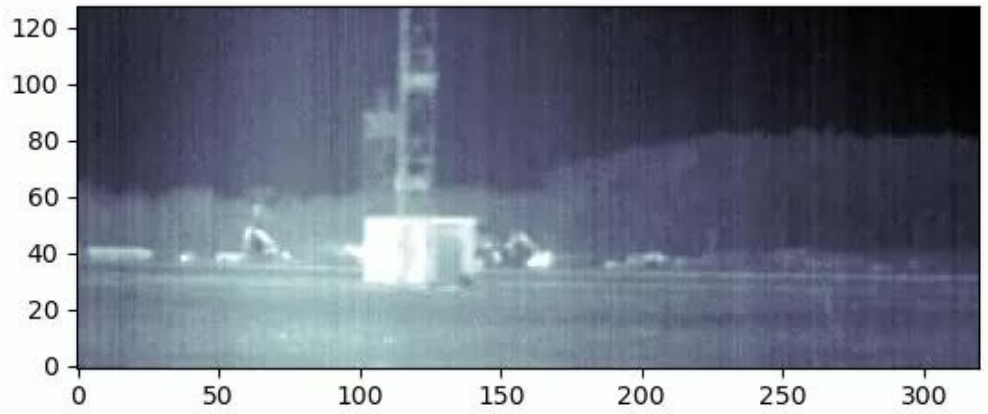

Tracking with low false positives

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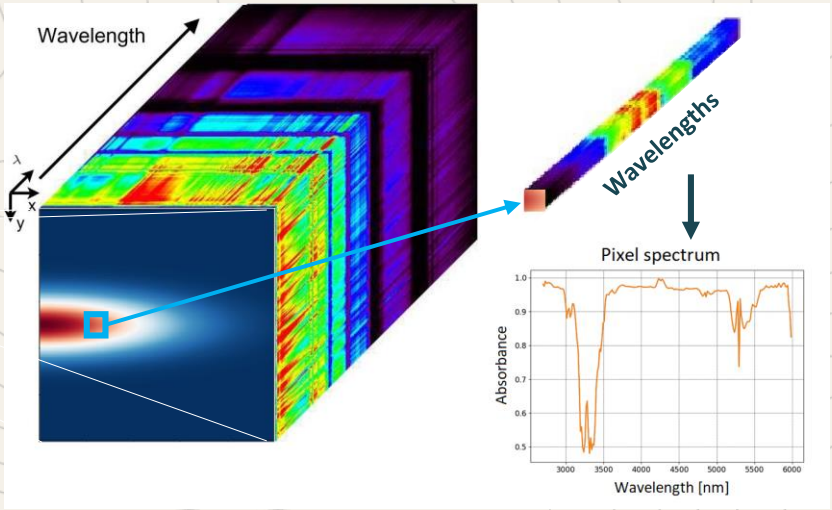
Use case: Jet Engine Monitoring

- **Problem:** Current jet engine health monitoring -> Time and cost inefficient
- **Challenge:** Monitor jet engine health in non-intrusive manner for preventive maintenance
- **Solution:** Use SWIR/MWIR hyperspectral imaging (HSI) and AI to assess jet engine health



AI algorithms for HSI image analysis

Condition OK

Needs maintenance

- Identify patterns and anomalies that may indicate potential maintenance issues
- Need large sample size under high range of conditions -> Use simulations and test engine measurements

Pacific Dragon 2022

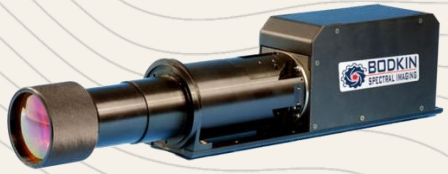
- July 22nd-August 15th 2022 Pacific Missile Range Facility Hawaii
- Scan a moving object from a distance of 3 km until about 12 km.
- Spectral characteristics of the propulsion plume

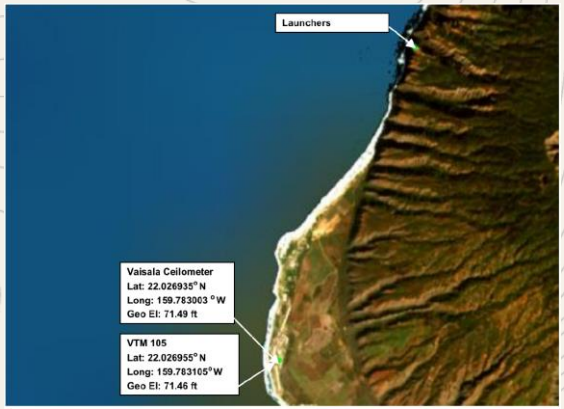
  → Identify type of missile
- Develop algorithms that can detect and classify ballistic missiles

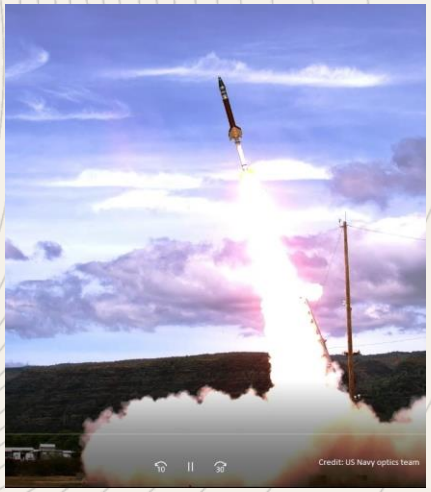
Event	Launching date	Missile type	Stage burn (sec)
1	9th August 2022	Terrier Oriole	6
2B	11th August 2022	Lynx Orion	35-40

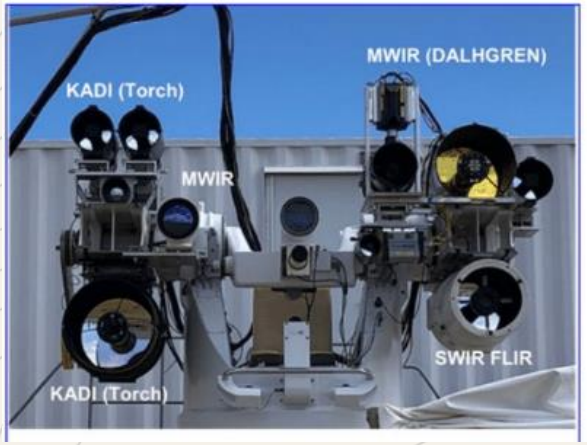
Requirements:

Detection distance:	3 to 12 km
Spectral bands:	60 bands
Spectral range:	3.3µm – 5.5µm
Number of pixels:	4 x 6 or 6 x 8
Frequency:	60 frames/s









Versatile Tracking Mount (VTM)

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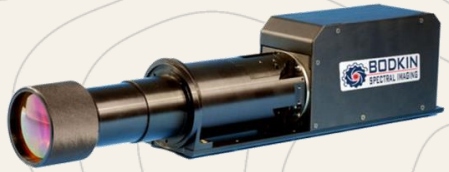
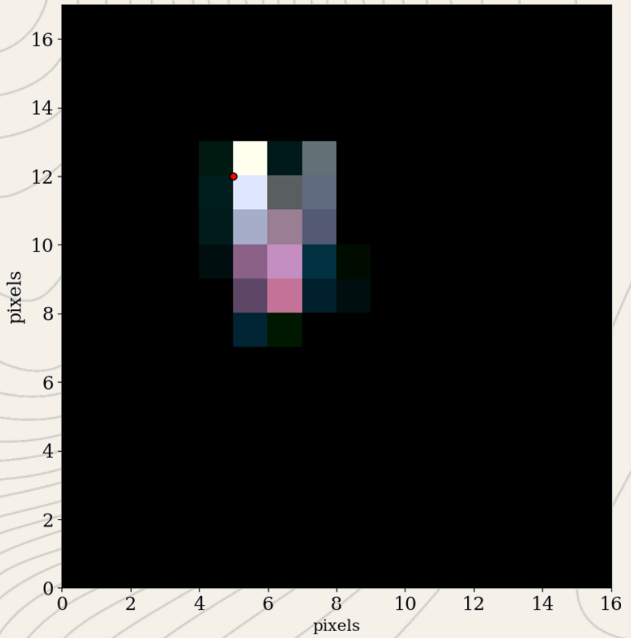
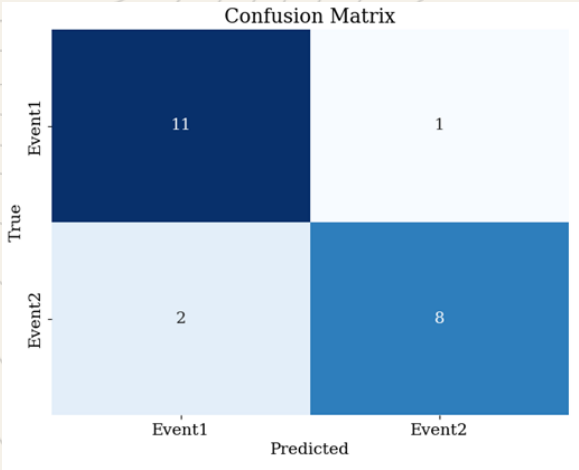
Pacific Dragon 2022

- Bodkin's MWIR-60 HSI:
  - 60 spectral bands covering 3-5µm
  - 16x17 pixels
- 85 useful spectral pixels
  - 40 for event 1 -> < 0.40% of total spectra
  - 45 for event 2 -> < 0.55 % of total spectra
- ML model can be trained to differentiate between events -> 86% accuracy
- Can be improved with better algorithms, more data, higher resolution data

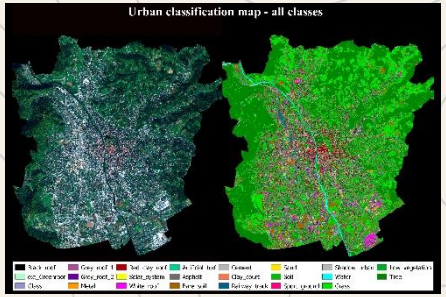






Hyperspectral applications for Defense

Surveillance and Reconnaissance



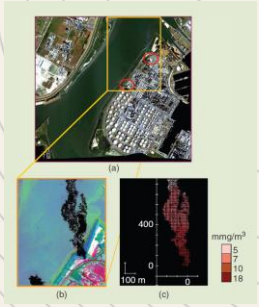
https://avt-as.eu/en/products/hyperspectral-imaging/

Camouflaged target Detection

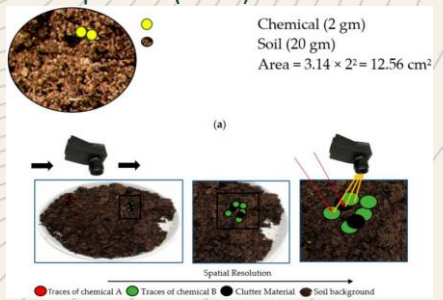
Hupel, T.; Stütz, P. Adopting Hyperspectral Anomaly Detection for Near Real-Time Camouflage Detection in Multispectral Imagery. Remote Sens. 2022, 14, 3755. https://doi.org/10.3390/rs14153755

Target Composition Analysis

https://i2kdefense.com/inflatable-decoys-and-targets/

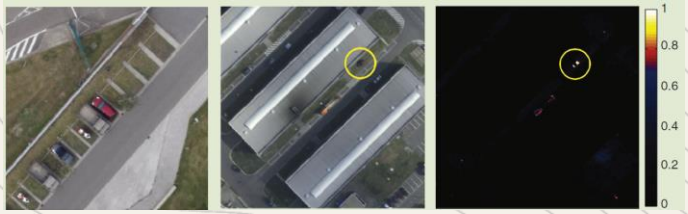


Explosive (trace) detection



Chaudhary S, Ninsawat S, Nakamura T. Non-Destructive Trace Detection of Explosives Using Pushbroom Scanning Hyperspectral Imaging System. Sensors (Basel). 2018 Dec 28;19(1):97. doi: 10.3390/s19010097. PMID: 30597901; PMCID: PMC6339093.

Target rediscovery



M. Shimoni, R. Haelterman and C. Perneel, "Hypersectral Imaging for Military and Security Applications: Combining Myriad Processing and Sensing Techniques," in IEEE Geoscience and Remote Sensing Magazine, vol. 7, no. 2, pp. 101-117, June 2019, doi: 10.1109/MGRS.2019.2902525.

...

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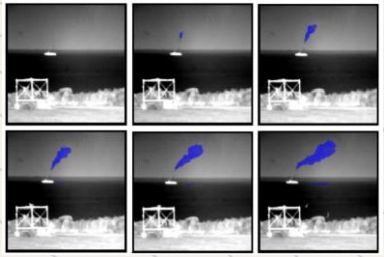
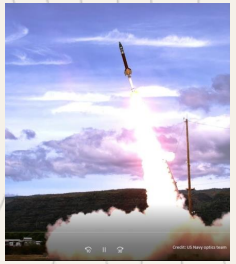
Chemical Agent Detection

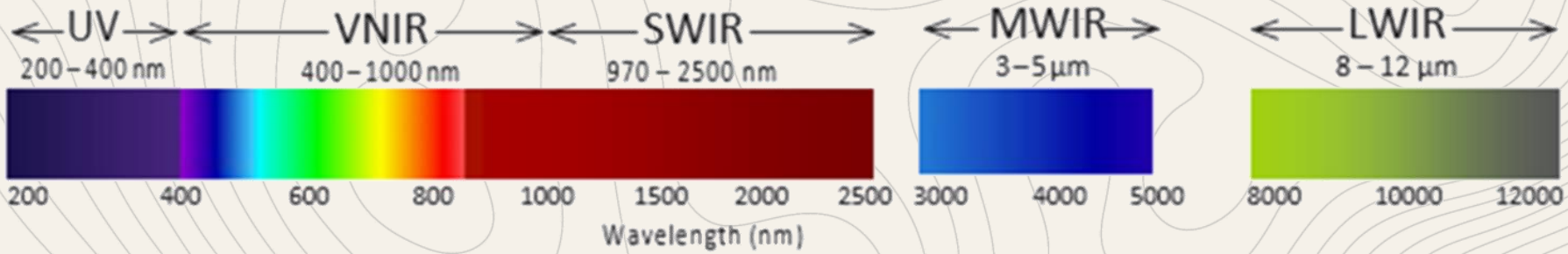


Vincent Farley, Alexandre Vallières, André Villemaire, Martin Chamberland, Philippe Lagueux, Jean Giroux, "Chemical agent detection and identification with a hyperspectral imaging infrared sensor," https://doi.org/10.1117/12.736864

Ballistic Missile Defense



Applications for Defense



MILITARY APPLICATION	MILITARY OPERATION	TYPE	SPECTRAL RANGE	PLATFORM
Gathering information about the battle field	Situation awareness	Strategy	VNIR, SWIR, and LWIR	Airborne and spaceborne
	Reconnaissance	Tactical	VNIR, SWIR, and LWIR	Field, airborne, and spaceborne
	Surveillance	Strategy and tactical	VNIR, SWIR, and LWIR	Field, airborne, and spaceborne
Discrimination between targets and decoys	Reconnaissance	Tactical	VNIR and LWIR	Field, airborne, and spaceborne
Defeating camouflage	Reconnaissance	Tactical	VNIR, SWIR, MWIR, and LWIR	Field, airborne, and spaceborne
Early warning for long-range missiles	Reconnaissance	Tactical	MWIR and LWIR	Field, airborne, and spaceborne
Detection of WMDs	Reconnaissance	Tactical	MWIR and LWIR	Field, airborne, and spaceborne
Detection of landmines	Situation awareness	Tactical	VNIR, SWIR, MWIR, and LWIR	Field and airborne

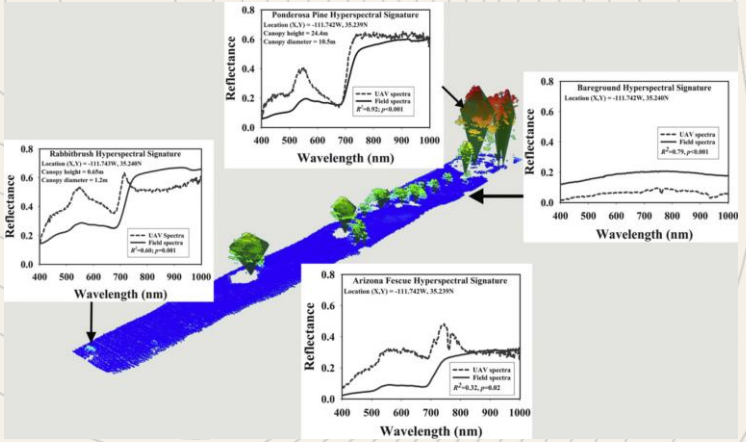
M. Shimoni, R. Haelterman and C. Perneel, "Hypersectral Imaging for Military and Security Applications: Combining Myriad Processing and Sensing Techniques," in IEEE Geoscience and Remote Sensing Magazine, vol. 7, no. 2, pp. 101-117, June 2019, doi: 10.1109/MGRS.2019.2902525.

In conclusion

- HSI has wealth of military applications
- Detailed spatial and spectral information:
  - Identify and quantify presence of material
  - High accuracy classification
  - Target Composition Analysis -> discrimination of real target and decoys
- Remote and non-destructive technique
- Evolving field (sensor technology, data processing algorithms, and machine learning)
- Increasingly being combined with other imaging systems (e.g., LiDAR)

Disadvantages

- Sensor Cost
- Amount of data -> ML
- Interpretability
- Atmospheric effects
- Penetration depth



Temuulen S. et al, UAV lidar and hyperspectral fusion for forest monitoring in the southwestern USA, Remote Sensing of Environment, Volume 195, 2017,

Cubert hyperspectral

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