

#### Hyperspectral Vision for Industrial Applications

Advantages, challenges and example applications of hyperspectral imaging in industry.







### Outline

- Hyperspectral vision
- Data processing
- Applications
- Implementation



#### Hyperspectral imaging





### Spectral imaging



- A few broader wavebands
- Gaps between the bands
- Targeted application

- Hundreds of small wavebands
- No gap between the bands
- Complete spectral analysis







#### Spatial scanning (pushbroom)



#### https://imt.kit.edu





#### Spectral scanning (e.g. filterwheel)



Spectrocam



#### **Snapshot (e.g. mosaic)**

Filter I	Filter 2	Filter 3
I 130	1150	1170
nm	nm	nm
Filter 4	Filter 5	Filter 6
I 200	I 220	1300
nm	nm	nm
Filter 7	Filter 8	Filter 9
I 400	1480	1660
nm	nm	nm

1.30	1.32	1.34	1.36
um	um	um	um
1.38	1.40	1.42	L44
um	um	um	um
1.46	1.48	1.50	1.52
um	um	um	um
1.54	1.56	1.58	1.60
um	um	um	um





1600



Spatio-spectral (e.g. filter-on-chip)







#### Manufacturers



HySpex, Oslo, Norway



Specim, Oulo, Finland



https://www.specim.com/

https://www.hyspex.com/



#### **Spectral ranges**



#### Infrared example: water

3 fundamental vibrational modes: 3n-6 = 3.



Symmetric stretching ( $\nu_1$ ) 2735 nm



Bending scissoring (v<sub>2</sub>) 6270 nm

> 1875 nm is v2 + v3 1449 nm is v1 + v3 1135 nm is v1 + v2 + v3 942 nm is 2v1 + v3



Asymmetric stretching (v<sub>3</sub>) 2662 nm

#### Addendum:

The combination bands wavelengths of water vapor have been corrected. Also, the graph is for liquid water at 27°C, so the absorption peaks don't match the water vapor. See Workman and Weyer 2007





#### **Spectral ranges**



Black Body Emission Curves of the Sun and Earth

https://scienceofdoom.files.wordpress.com/2009/11/blackbody\_curve-sun-earth.jpg

# Data processing



### Data processing



- Absorbance:  $A_{\lambda} = c l \varepsilon_{\lambda}$  (Beer Lambert's law)
- Pre-processing / scatter correction.
- Chemometrics.
- Machine learning / Al.

Concentration c (mol L<sup>-1</sup>) Length of light path I (cm) Molar absorption coefficient ε (L mol<sup>-1</sup>cm<sup>-1</sup>)



#### **Application overview**





# Waste sorting





#### Textile waste sorting Acryl Synthetic PE Cotton Plant based Linen Silk Animal based Wool 1,00 ACRYL POLYESTER COTTON 0,94 LINEN REFLECTANCE \* 10 000 WOOL/ACRYL SILK COTTON 2 0,88 ALPACA MERINO 0,82 0,76 0,70 1000 1200 1600 1400 nm

RGB

https://www.specim.com/hyperspectral-imaging-reducing-textile-waste/

Prediction

#### **Plastic sorting**







Sorting PE+PP

PP

PE (98%)





#### Plastic sorting in MWIR





# Quality control

### Metal industry





A Konica Minolta Company





Specim / Wikipedia

#### **Pharmaceutics**











#### Dry film thickness





Figure 2. Mean reflectance spectra for all 8 samples (same color coding as in Figure 1). Changes in dry film thickness result in a change in spectral properties of the coating.

https://www.hyspex.com/use-cases-application-notes/coating/





#### Cocoa beans



Figure 3: Classification image of the cocoa bean samples.
Good beans, 

Under-fermented beans, 
Slaty beans, 
Other low-quality beans.





#### **Fish inspection**









## Gas detection





### Monitoring SO<sub>2</sub> from ships





StLawrence -735







50



100

150

N R C E

19: StLawrence -735





#### Methane detection (LWIR)









#### $CH_4$ Flux > 0.5 g/s

Assuming the following conditions: <u>Flight Parameters</u>: Flight altitude: ~ 350m Flight speed: [65 75] knots <u>Weather conditions</u>: Local wind speed: <7km/hr Thermal Contrast: > 4°C <u>Instrument settings</u>: Inspection track width: 30m

https://www.telops.com/products/hyperspectral-cameras/



#### Methane detection (SWIR)





# Geology



https://www.m4mining.eu/

#### **Mineral detection**







http://terracoregeo.com





#### **Mineral detection**

Туре	Silicate Structure	Mineral Group	Example	VNIR Response	SWIR Response	LWIR Response
Silicates	Inosilicates	Amphibole	Actinolite	Non-Diagnostic	Good	Moderate
		Pyroxene	Diopside	Good	Moderate	Good
	Cyclosilicates	Tourmaline	Elbaite	Non-Diagnostic	Good	Moderate
	Nesosilicates	Garnet	Grossular	Moderate	Non-Diagnostic	Good
		Olivine	Forsterite	Good	Non-Diagnostic	Good
	Sorosilicates	Epidote	Epidote	Non-Diagnostic	Good	Moderate
	Phyllosilicates	Mica	Muscovite	Non-Diagnostic	Good	Moderate
		Chlorite	Clinochlore	Non-Diagnostic	Good	Moderate
		Clay Minerals	Illite	Non-Diagnostic	Good	Moderate
			Kaolinite	Non-Diagnostic	Good	Moderate
	Tectosilicates	Feldspar	Orthoclase	Non-Diagnostic	Non-Diagnostic	Good
			Albite	Non-Diagnostic	Non-Diagnostic	Good
		Silica	Quartz	Non-Diagnostic	Non-Diagnostic	Good
Non-Silicates	Carbonates	Calcite	Calcite	Non-Diagnostic	Moderate	Good
		Dolomite	Dolomite	Non-Diagnostic	Moderate	Good
	Hydroxides	and the section of th	Gibbsite	Non-Diagnostic	Good	Moderate
	Sulphates	Alunite	Alunite	Moderate	Good	Moderate
			Gypsum	Non-Diagnostic	Good	Good
	Borates		Borax	Non-Diagnostic	Moderate	TBD
	Halides	Chlorides	Halite	Non-Diagnostic	TBD	TBD
	Phosphates	Apatite	Apatite	Moderate	Non-Diagnostic	Good
	Hydrocarbons		Bitumen	TDB	Moderate	TBD
	Oxides	Hematite	Hematite	Good	Non-Diagnostic	Non-Diagnostic
		Spinel	Chromite	Non-Diagnostic	Non-Diagnostic	Non-Diagnostic
	Sulphides		Pyrite	Non-Diagnostic	Non-Diagnostic	Non-Diagnostic







**Characterization of Middle Bakken** 

http://terracoregeo.com/why-use-terracore/oil-and-gas/



# **Condition monitoring**



### Remote inspection of wooden utility poles



False RGB

PCA RGB





# Remote inspection of wooden utility poles



Bad



Good



Score 0.6



Score 0.1



# Health and medicine



### Viral infection



Air flow

Hospital rooms



Mol = Number of virus / Number of cells



#### **Detection of asbestos**







0.45

Prediction Probability Images

(a)



(c)

(b)



1.5

Giuseppe Bonifazi and Silvia Serranti, "Hyperspectral imaging for asbestos identification in cement products" https://spie.org/news/6645-hyperspectral-imaging-for-asbestos-identification-in-cement-products#\_=\_

# Implementing hyperspectral vision

### Hyperspectral

Advantages:

- Versatile, identifies most materials.
- Non-invasive and non-destructive.
- Online and real-time.
- Green and digital.

#### Disadvantages:

- It is a project.
- Big and complex data.
- Expensive camera.







### Or go multi-spectral

Make it application-spesific:

- Identify the (most) relevant parts of the spectrum.
- Determine the center and width of the spectral bands.
- Lighting can also be more targeted.
- Simpler and cheaper.



# Thank you. Takk. /lerci. Gracias. Obrigado.

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