HYPERSPECTRAL IMAGING

TECHNOLOGY – APPLICATIONS - FUTURE

GERHARD STANZEL, HSI TECHNOLOGY SPECIALIST
STEMMER IMAGING
HYPERSPECTRAL IMAGING

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AGENDA

1. Technology
   What is it?
   Hardware
   Software

2. Applications
   Overview
   Colour
   Humidity
   Foreign bodies

3. Future
   Standardisation
   Hyperspectral Apps
   Spectroscopy for everybody
WHAT IS HYPERSPECTRAL IMAGING?

HSI combines spectroscopy with imaging

- **Spectroscopy** and spectrography are terms used to refer to the measurement of radiation intensity as a function of wavelength.

- Hyperspectral imaging collects and processes *spatially resolved information from across the electromagnetic spectrum*.

- The goal of hyperspectral imaging is to **obtain the spectrum for each pixel in the image of a scene**.

- A hyperspectral image is a 3-dimensional datacube with two spatial and one spectral axis.

- Hyperspectral imaging can **take advantage of the spatial relationships** among the different spectra in a neighborhood.
WAVELENGTH REGIONS

Das für den Menschen sichtbare Spektrum (Licht)

<table>
<thead>
<tr>
<th>Gamma rays</th>
<th>X-rays</th>
<th>Ultra-Violett</th>
<th>Visible</th>
<th>Near IR</th>
<th>Infrared MW/LW</th>
<th>Far IR</th>
<th>Tera-hertz</th>
<th>Micro-wave</th>
<th>Radio-waves</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v$ (cm$^{-1}$)</td>
<td>$10^{10}$</td>
<td>$10^8$</td>
<td>$10^6$</td>
<td>25.00</td>
<td>14,200</td>
<td>4,000</td>
<td>650</td>
<td>12</td>
<td>0.05</td>
</tr>
<tr>
<td>$\lambda$ (nm)</td>
<td>$10^{-4}$</td>
<td>$10^{-2}$</td>
<td>1</td>
<td>400</td>
<td>700</td>
<td>2,500</td>
<td>15,400</td>
<td>830,000</td>
<td>$2 \times 10^8$</td>
</tr>
</tbody>
</table>

Stimulation of bonding electrons and ionisation

Stimulation of nonbonding electrons

Overtones of molecular vibrations

Molecular vibrations

Molecular rotation

Source: https://de.wikipedia.org/wiki/Elektromagnetisches_Spektrum
WHY IS THERE ABSORBANCE?

- **Infrared**: Stimulation of molecular vibrations, depending from oscillating masses and chemical bond strengths

- Location of the absorption bands provide information on chemical functional groups

- Vibrations of a methylene group (-CH₂-) in a molecule:

  - Symmetrical stretching
  - Asymmetrical stretching
  - Scissoring (Bending)
  - Rocking
  - Wagging
  - Twisting

Source: https://en.wikipedia.org/wiki/Molecular_vibration
WHY SWIR?

Vibrational absorbance bands are stronger in the SWIR range

Assignment of the IR vibrational absorption spectrum of liquid water

<table>
<thead>
<tr>
<th>Wavelength cm⁻¹</th>
<th>Assignment</th>
<th>Wavelength nm</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>3650</td>
<td>aH₂O + aH₂O</td>
<td>3320</td>
<td>aH₂O + aH₂O; a + b = 2</td>
</tr>
<tr>
<td>11950</td>
<td>aH₂O + aH₂O</td>
<td>11340</td>
<td>aH₂O + aH₂O; a + b = 3</td>
</tr>
<tr>
<td>13530</td>
<td>aH₂O + aH₂O</td>
<td>13840</td>
<td>aH₂O + aH₂O; a + b = 4</td>
</tr>
<tr>
<td>16500</td>
<td>aH₂O + aH₂O</td>
<td>16800</td>
<td>aH₂O + aH₂O; a + b = 5</td>
</tr>
<tr>
<td>1700</td>
<td>aH₂O + aH₂O</td>
<td>17300</td>
<td>aH₂O + aH₂O; a + b = 6</td>
</tr>
<tr>
<td>1780</td>
<td>aH₂O + aH₂O</td>
<td>18100</td>
<td>aH₂O + aH₂O; a + b = 7</td>
</tr>
<tr>
<td>1800</td>
<td>aH₂O + aH₂O</td>
<td>18300</td>
<td>aH₂O + aH₂O; a + b = 8</td>
</tr>
<tr>
<td>1970</td>
<td>aH₂O + aH₂O</td>
<td>19900</td>
<td>aH₂O + aH₂O; a + b = 9</td>
</tr>
<tr>
<td>2090</td>
<td>aH₂O + aH₂O</td>
<td>21100</td>
<td>aH₂O + aH₂O; a + b = 10</td>
</tr>
</tbody>
</table>

Note that a and b are integers ≥ 0

Source: http://www1.lsbu.ac.uk/water/water_vibrational_spectrum.html
HYPERSPECTRAL HARDWARE

Camera, spectrograph, lens, illumination, calibration target, PC, Grabber, Cables, Supplies, Housings…

Sources: Metaphase, Specim, Allied Vision, Kowa, Sphere Optics, LLA, Autovision
HSI – ACQUISITION TECHNOLOGIES

1. wavelength scanning method (A to D)
2. spatial sampling (E)
3. temporal sampling (F)
4. quasi wavelength scan and spatial sampling (compromise, G)

Sources: https://en.wikipedia.org/wiki/Hyperspectral_imaging
Paul Gerald Dittrich - Spectronet
ADVANTAGE OF HSI COMPACT CAMERAS

Interoperable - UNIFIED, COMPARABLE DATA

- Unified wavelength calibration guarantees that the data received from different units is comparable.
- Different units in one system work seamlessly together, and extending the system by adding cameras is easy - there is no need for calibration.

<table>
<thead>
<tr>
<th>SPECIM FX 10</th>
<th>SPECIM FX 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral range</td>
<td>400 – 1000 nm</td>
</tr>
<tr>
<td>Spectral bands</td>
<td>224</td>
</tr>
<tr>
<td>Spectral FWHM</td>
<td>5.5 nm</td>
</tr>
<tr>
<td>Spatial sampling</td>
<td>1024 px</td>
</tr>
<tr>
<td>Frame Rate</td>
<td>330 FPS (full frame)</td>
</tr>
<tr>
<td>FOV</td>
<td>38 °</td>
</tr>
<tr>
<td>F-number</td>
<td>F/1.7</td>
</tr>
<tr>
<td>Camera SNR</td>
<td>600:1</td>
</tr>
<tr>
<td>Camera Interface</td>
<td>GigE Vision or CameraLink</td>
</tr>
<tr>
<td>Dimensions</td>
<td>150 x 85 x 71 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>1.4 kg</td>
</tr>
<tr>
<td>Integrated shutter and order blocking filter</td>
<td>Integrated shutter</td>
</tr>
</tbody>
</table>

Source: Specim
HYPERSPECTRAL SOFTWARE

Perception Studio by Perception Park

- Easy to use environment for hyperspectral application development
- Real Time processing of hyperspectral data in Perception Core
- GigE vision compatible output streams

www.perception-park.com
HYPERSPECTRAL SOFTWARE

Perception Studio by Perception Park

Perception Environment – Introduction

- Modular
- Extendable
- Windows and Linux support
- Compatible with embedded boards (Nvidia Jetson)

www.perception-park.com
INDUSTRIAL SWIR HSI SETUP

- Inspects since Oct 2017
- Speed 1 m/s
- 145 inspections/min
- Processing of chemical colour images in Sherlock

Video link:
Non-transparent food package

Non-transparent printed foil

Spectral segmentation of fat

Broken seal due to cheese inclusion

Spectral image of cheese in polymer package

SOLUTION BY Minebea intec

STEMMER IMAGING
APPLICATIONS

HSI market and segmentation

Segmentation of spectral imaging applications

Source: Tematys CHII 2018
APPLICATIONS

- Damages
- Sweetness
- Diseases
- Safety
- Contaminations
- Quality
- Foreign body inspection

- Colour
- Humidity
- Food grading & control
- Quality assurance

- API content
- API distribution
- Pharma

- Environmental Monitoring
- Remote Sensing

- Life Sciences / Biomedical
- Forensics

- Thin Film measurement
- Chemical industry

- Military

- Sorting
- Food
- Minerals
- Recycling

- Tumor detection
- Wound inspection
- Melanoma classification

- Medical

- Agriculture
- Precision Farming
- Phenotyping

- Art Inspection

- Currency and document inspection
- Geology
- Display inspection
- Process Analytics
APPLICATIONS - COLOUR

Precise determination of colour values

- Exact colour evaluation
- Existing colour measurement standards (CIE)
- L*a*b calculation based on spectral information
- Right combination of camera, illumination, software
- Colour-optimized FX10c
- GEV-compatible L*a*b output stream with Perception Studio

<table>
<thead>
<tr>
<th>Sample</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62.8</td>
<td>11.1</td>
<td>33.8</td>
</tr>
<tr>
<td>2</td>
<td>63.0</td>
<td>11.0</td>
<td>33.5</td>
</tr>
<tr>
<td>3</td>
<td>52.3</td>
<td>14.2</td>
<td>30.3</td>
</tr>
<tr>
<td>4</td>
<td>61.0</td>
<td>12.2</td>
<td>34.2</td>
</tr>
<tr>
<td>5</td>
<td>47.5</td>
<td>14.1</td>
<td>29.2</td>
</tr>
<tr>
<td>6</td>
<td>61.4</td>
<td>11.9</td>
<td>34.6</td>
</tr>
<tr>
<td>7</td>
<td>51.3</td>
<td>13.7</td>
<td>30.4</td>
</tr>
<tr>
<td>8</td>
<td>43.1</td>
<td>14.4</td>
<td>25.4</td>
</tr>
</tbody>
</table>

Achieve light spectral distribution which couldn’t be expressed with conventional LEDs!
APPLICATIONS - HUMIDITY

Humidity quantification

- Important parameter for food, fruits, bakery, paper, wood
- Weak absorbance at ~970nm
- Stronger absorbance >1450nm
- For quantitative values reference Analytics needed (eg LoD – loss on drying)
APPLIED SENSING – FOREIGN BODIES

Foreign Body inspection on food / produce surface

- Contaminations with Glas / Metal => X-Ray / electromagnetic detection
- Not suitable for plastic contaminants => not detectable because of low density
- Surface contaminants can be detected by hyperspectral imaging
HYPERSPECTRAL SYSTEM
DEFINED BY APPLICATION REQUIREMENTS

Which HSI System? – It depends… on the requirements of the application

- Acquisition technology
- Resolution in spatial and spectral domain, SNR, dynamic range, framerate
- Object properties (e.g. water content or added carbon black, surface characteristics, size, …)
- Wavelength range - UV, VIS-NIR, SWIR, MWIR, LWIR and corresponding penetration depth
- Illumination - Halogen / LED / others, shape and angle of illumination
- Illumination setup - Reflection, Transmission, Interactance
- SWaP – Size, Weight, and Power (consumption)
HYPERSPECTRAL SYSTEM

SUMMARY

Keep in mind...

- You always measure a mixture of morphological and chemical characteristics – there’s always scattering and absorption

- Illumination is important and all possibilities have pros and cons

- Like in machine learning the selection of training data for a model is important

- Models have to be validated to get sure you’re measuring right

- Sensitivity is limited – NIR spectroscopy is no trace analysis

- Particle size has a wavelength dependent influence on the measured spectra (can also be used for analysis)

- Robustness and Precision depend on the application and have to be evaluated
FUTURE - STANDARDISATION

IEEE P4001

- Standard for Characterization and Calibration of Ultraviolet through Shortwave Infrared (250 nm to 2500 nm) Hyperspectral Imaging Devices

- Hyperspectral imaging is an innovative and exciting technology that hold incredible diagnostic, scientific and categorization power. Current industry innovation is a testament to the creative power and imagination of the diverse community seeking to optimize this technology. However, fundamental instrument performance is not well characterized, well understood or well represented to suit distinct application endeavors or commercial market expectations.

- The standard defines terminology, device classes, laboratory tests, characterization and calibration methodologies and recommended practices for application-specific tasks. Initial work is limited to devices that cover the 0.25-2.50um spectral region.

- [http://sites.ieee.org/sagroups-hyperspectral/](http://sites.ieee.org/sagroups-hyperspectral/)
FUTURE - STANDARDISATION

EMVA 1288

Future Work
Ongoing work includes:

- Software and hardware certification
- Shutter efficiency
- Sensor/lens interface including sensor MTF
- Trigger delay and jitter
- Extension to UV, SWIR, polarization and hyperspectral imaging
- HDR sensors and cameras
- More detailed analysis of dark current

FUTURE - SMART EMBEDDED HSI

Application focused devices

- Compact sensors
- Embedded systems
- Simplified software handling
- Preconfigured
- Intuitive setup
- Easy to operate
- Reduced complexity
FUTURE - SPECTROSCOPY FOR EVERYBODY

- Smartphone Spectrometers => already exist
  (Changhong H2 (2017) ~433$)

- Based on food scanner “Scio”

- Cloud-based data analysis

- Result matters – not technology
FUTURE OF HSI IN INDUSTRY

- Reduce price, complexity, (size)
- Improve resolution and speed
- LED based spectral illuminations (Osram, Metaphase, CCS natural white)
- Application focused systems – smart embedded HSI cameras with integrated App
- Awareness about HSI technology and it’s possibilities (also driven by consumer applications)
- Success stories lead to wider adaption
- New technological possibilities (sensors, miniaturization, …)
DO YOU WANT TO KNOW MORE?

- Hyperspectral Imaging Training
  21st Nov 2019 in Puchheim near Munich / Germany

- CHII 2020 – conference on hyperspectral imaging in industry organized by Perception Park

More information about Machine Vision Trainings at the EUROPEAN IMAGING ACADEMY:

www.stemmer-imaging.de/en/events/training-events
THANK YOU FOR YOUR TIME

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