CMOS BASED HYPERSONTAL IMAGING
FOR COMPACT / LOW-COST / HIGH-VOLUME IMAGING SPECTROSCOPY

Activity update - April 2016
WHY DO WE NEED HYPERSONTRAL IMAGING?

to improve vision and discrimination power ...

... by using spectral dimension of objects being imaged
SPECTRAL IMAGING OPEN ONE NEW DIMENSION

POINT SPECTROSCOPY

Accurate spectral analysis of one spatial pixel only

COLOR IMAGING

Seeing RGB colors of one image only

HYPERSPECTRAL IMAGING

spectral signature images revealing objects chemical composition
one wavelength dimension for each pixel ...
CONVERGENCE OF IMAGING & SPECTROSCOPY

IMAGING

High speed, high spatial resolution

SPECTROSCOPY

Single point with highest spectral resolution

IMEC approach: spectral filters on multiple pixels

RGB filters on multiple pixels

Mosaic pattern

Tiled pattern

Line pattern
SPECTRAL FILTERS APPLIED TO IMAGE SENSOR WAFERS BY CMOS SEMICONDUCTOR PROCESS

IMEC hyperspectral filter structures processed at wafer-level on top of commercial CMOS image sensor wafer (here on CMOSIS's CMV2000 & CMV4000 sensors)
we design & manufacture spectral filters directly onto image sensor pixels ...

... based on CMOS compatible semiconductor process
OPTICAL FILTERS DEPOSITED & PATTERNED @ PIXEL LEVEL!

- down to 2um pixels
- 1 to 200+ colors
- Class I clean (no particles)
- 1B€ pilot-line factories on-site
- Advanced CMOS processes (22nm → 7nm)
- R&D to production environment
- Class 1 processing for ‘clean’ filter integration
E.G. OF POSSIBLE APPROACH FABRY-PEROT SPECTRAL FILTERS

Wavelength selection depends on cavity length $L$

$$k\lambda = 2nL\cos \theta$$

Narrow-band & high transmission efficiencies spectral filters

Different cavity heights = different spectral wavelengths captured!

$T_x (%)$

FWHM ~ 5-20 nm

Wavelength (nm)
CUSTOM HYPERSPECTRAL IMAGING SOLUTIONS

- Spectral filters can be integrated onto commercial image sensor wafers

- Optical filters & imager can be customized to match final application requirements

- Fill the sensor ONLY with selected bands of interest

- Filter response
  - FWHM
  - OD
  - \( \lambda_1 \), \( \lambda_2 \), \( \lambda_n \)

- Continuous Line-scan
- Custom Line-scan
- Snapshot Tiled
- Snapshot Bayer Mosaic
OFF-THE-SHELF SPECTRAL IMAGING SENSORS

RGB

RGB + NIR

Multi-spectral

Hyperspectral

70+ commercial vendors

(in development)

4 bands

Snapshot mosaic & tiled

16 / 25 / 32 / 40+ bands

Linescan

100 / 150+ bands
LINESCAN 100+BANDS HSI SENSOR DESIGN (GEN1)

- **Key specifications**
  - **Spectral resolution**: 100+ bands in 600-1000nm
  - **FWHM**: ~ 10-15nm
  - **Spatial resolution**: 2048 pixels x length of scan
  - **Speed**: up to 340 fps (full sensor frame)
LINESCAN 150+BANDS HSI SENSOR DESIGN (GEN 2)

Key specifications
- **Spectral resolution**: 150+ bands in 470-925nm
- **FWHM**: ~ 10-15nm
- **Spatial resolution**: 2048 pixels x length of scan
- **Speed**: up to 340 fps (full sensor frame)
SNAPSHOT TILED 32 BANDS HSI SENSOR DESIGN

- **Key specifications**
  - **Spectral resolution**: 32 bands in 600-940nm
  - **FWHM**: ~ 10-15nm
  - **Spatial resolution**: 256x256 RAW per band
  - **Speed**: up to 340 fps (full sensor frame)
SNAPSHOT MOSAIC 4X4 HSI SENSOR DESIGN

- **Key specifications**
  - **Spectral resolution**: 16 bands in 460-630nm
  - **FWHM**: ~10-15nm
  - **Spatial resolution**: 512x256 RAW per band
  - **Speed**: up to 340 fps (full sensor frame)
SNAPSHOT MOSAIC 5X5 HSI SENSOR DESIGN

Snapshot mosaic sensor with 5x5 =25 bands
(from CMOSIS CMV2000 - without microlenses)

- Key specifications
  - Spectral resolution: 25 bands in 600-960nm
  - FWHM: ~ 10-15nm
  - Spatial resolution: 409x216 RAW per band
  - Speed: up to 340 fps (full sensor frame)
ROADMAP FOR OFF-THE-SHELF HSI SENSORS

**Snapshot ‘MOSAIC’**
- VIS 460-640nm (4x4 = 16 bands)
- NIR 600-975nm (5x5 = 25 bands)

**Snapshot ‘TILED’**
- GEN1 600-975nm (32 bands)

**LINESCAN ‘Wedge’**
- GEN1 600-975nm (100+ bands)

**VNIR**
- GEN2 470-925nm (150+ bands)
- GENI 1-1.7μm (100+ bands)

2013 | 2014 | 2015 | 2016 | 2017+
Bringing hyperspectral imaging...  
... to machine vision!
### ECOSYSTEM PARTNERS FOR HSI SENSOR CAMERA INTEGRATION

<table>
<thead>
<tr>
<th><strong>High speed camera</strong></th>
<th><strong>Flexible camera platform</strong></th>
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<tr>
<td>- Cameralink or CoaXPress interface</td>
<td>- Giga/Ethernet interface</td>
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<tr>
<td>- Compact optical design with ZIFF socket to swap different HSI sensors</td>
<td>- Focus on remote sensing, UAV agriculture &amp; machine vision</td>
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<tr>
<td>- Industrial, medical and global security</td>
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<th><strong>Smart camera</strong></th>
<th><strong>Embedded vision module</strong></th>
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<td>- GigeVision and Genicam compliant</td>
<td>- Giga/Ethernet interface</td>
</tr>
<tr>
<td>- A/B shaft encoder interface (RS-422 or HTL levels). FPGA pre-processing</td>
<td>- Motorized optics and Multi-camera head option</td>
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<tr>
<td>- Agriculture, food sorting and industrial applications</td>
<td>- Embedded HSI data processing include storage</td>
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<th><strong>USB 3.0 vision camera</strong></th>
<th><strong>Handheld mobile platform</strong></th>
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<tr>
<td>- High-speed USB3.0 camera</td>
<td>- First proof-of-concept of IMEC's HSI sensors integration to mobile</td>
</tr>
<tr>
<td>- Ultra compact camera: 26.4 x 26.4 x 21.2 mm</td>
<td>- Android OS open platform</td>
</tr>
<tr>
<td>- 27grams weight only!</td>
<td>- USB2.0 interface</td>
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HSI DEMO-KITS FOR EVALUATION
compact | pc-powered | ready-to-go!
HSI SOFTWARE TO SUPPORT APPLICATION DEVELOPMENT

- **License** available to all demo-kit customers & partners

- **Support** including installation, training and Q&A (remotely and on-site)

- **Source-code** available for OEM integration for the following blocks:
  - Cube registration
  - Reflectance calculation
  - Spectral corrections
HSI data-cube (after scan)

x 100+ spectral band images!

Sample spectras
(x3 pixels plotted)

Classified image
(extracting leaves only)
DRIVING APPLICATIONS FOR IMEC HSI

**Remote sensing**
- UAVs & cube-satellites for:
  - Precision agriculture
  - Environment monitoring
  - Terrestrial / maritime earth observation

**Life-science instrumentation**
- Imaging spectroscopy analyzers
- DNA sequencers / flow cytometers
- Water monitoring analyzers
- Blood / urine analyzers

**Machine vision / Optical sorting**
- Food sorting / quality grading
- Pharmaceutical defect inspection
- Industrial process control
- Bank-note inspection
- Print quality inspection

**Security / Surveillance**
- Industrial gas leaks monitoring
- Intrusion detection / authentication
- Forensics
- Anti-counterfeiting

**Medical imaging**
- Surgery-guided imaging
- Endoscopy
- Ophthalmology / retina imaging
- Wounds imaging
- Fluorescence microscopy

**Automotive & Transport**
- Night vision systems
- Fuel monitoring systems
- Driver drowsiness
... integration path into UAVs for precision agriculture
Soil analysis

Nutrient deficiency diagnostics

Grows monitoring

Disease and weeds alerts

Nutrient deficiency diagnostics

Yield prediction
LINESCAN SENSOR IN PRECISION AGRICULTURE

RAW image  
spectral image  
vegetation index map  
management zone map

acquire  
process  
interpret  
act
snapshot hyperspectral imaging in medical

e.g. supporting surgeons in smarter diagnostic of tissues
REAL-TIME OXYGENATION MAPS

Reconstructed Hb/HbO/HBT maps extracted from HSI snapshot mosaic
4x4 = 16bands HSI sensor on epileptic patient during brain surgery

View live video here → https://vimeo.com/132097972
ATM / BANK NOTE INSPECTION

Hyperspectral (5x5 mosaic NIR)

RGB

Courtesy of Perception Park Studio
LINELSCAN HSI SENSOR FOR RICE INSPECTION

Classification Training Set

Training Set of Hyperspectral signatures

Object–level classification + standard vision software processing

Principal Component Analysis
HIGH SPEED ANOMALIES DETECTION WITH 25+ BANDS SNAPSHOT MOSAIC SENSOR

spectra differ in the NIR range (> 700 nm). Spectra are loaded in the library.

Sample is moving in real-time

Sample of interest is identified in real-time

View live video here → https://vimeo.com/132098267
FOOD FRESHNESS MONITORING FOR FOOD QUALITY GRADING APPLICATIONS

- 100% inspection via gill’s blood spectrum
- Determine food quality freshness within few hours till 4 days
SAME TECHNOLOGY INDUSTRIAL → TO CONSUMER?

Remote sensing

Machine vision / Optical sorting

Medical imaging

Consumer

Life-science instrumentation

Automotive & Transport

Security / Surveillance

Consumer

Consumer

Consumer

Consumer

Consumer

connected health
HSI SOFTWARE IMAGE PROCESSING PIPELINE

Camera calibration, registration, synchronization, reflectance calculation...etc

Spectral un-mixing, smoothening, PCA, SVM, k-means clustering, ...etc

Visualization, GUI... etc

Pre-Processing

Feature Extraction & Selection

Feature Classification/Recognition

Post-Processing

Camera/Sensor Specific

Application Specific

IMEC can support these SOFTWARE / Application layers

Application Specific (to be developed for each platform)

HSI ‘cube’
IMEC COLLABORATION MODEL FOR DEVELOPING HSI SOLUTIONS, APPLICATIONS & MARKETS

- Spectral filter materials & Fab operations
- Sensor & Filter co-Design
- Camera & System Design
- Low level image proc. Firmware
- HSI image proc. SW
- Appli. SW
- Full system feasibility study
- Large data-sets & services

IMAGERY: imec