

초분광 카메라 기술과 응용

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- Linescan
- Mobile
- Drone

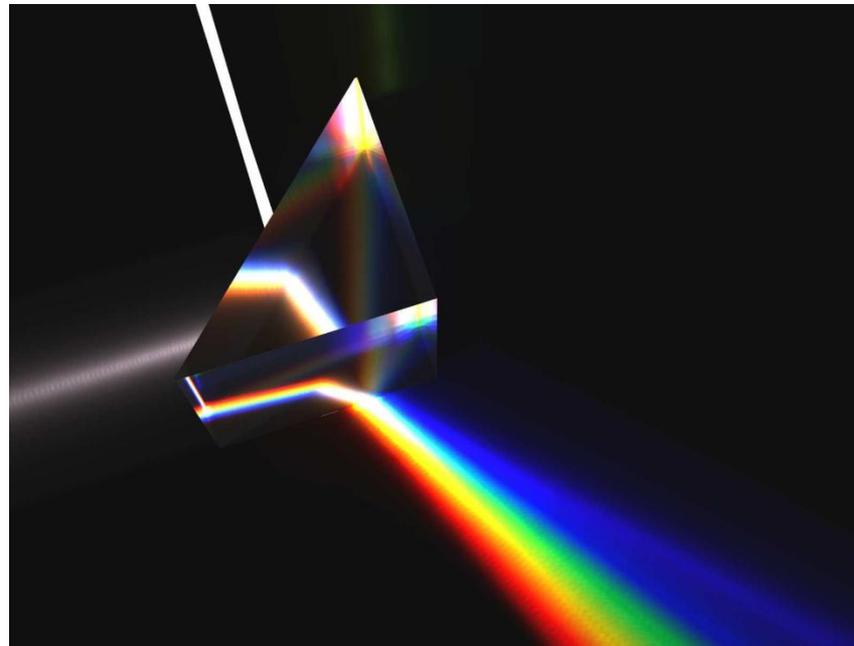
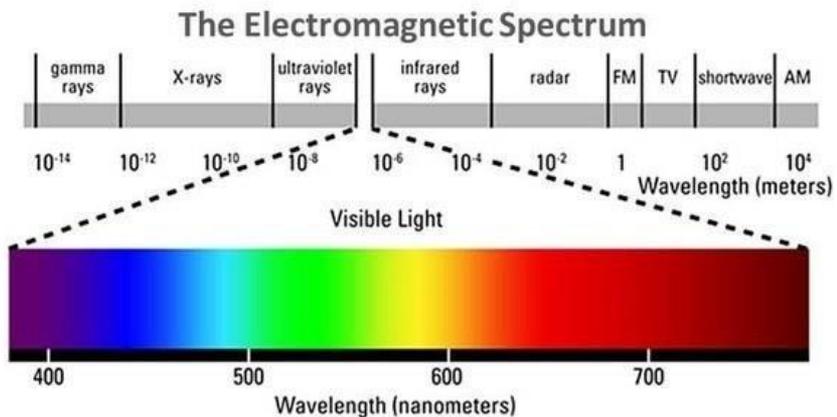
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- 농업 / 산림 / 지질
- 수질 / 수자원
- 환경 / 국방
- 문화재 / 토양
- 기타

1. 초분광 영상

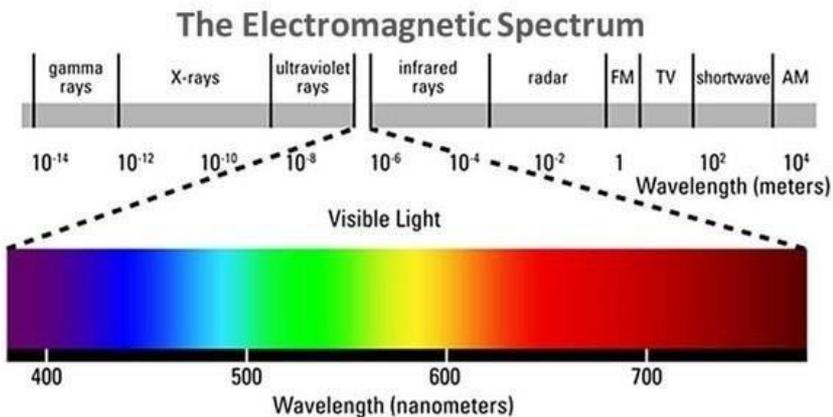
개요

- 스펙트럼 정보가 포함된 이미지

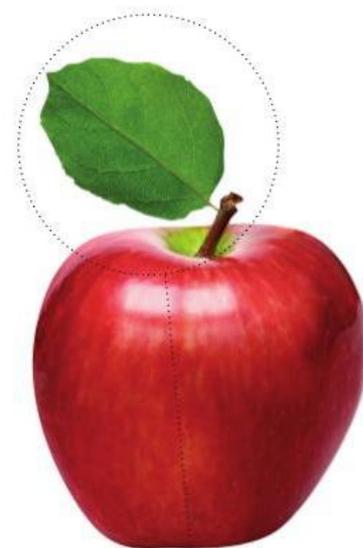


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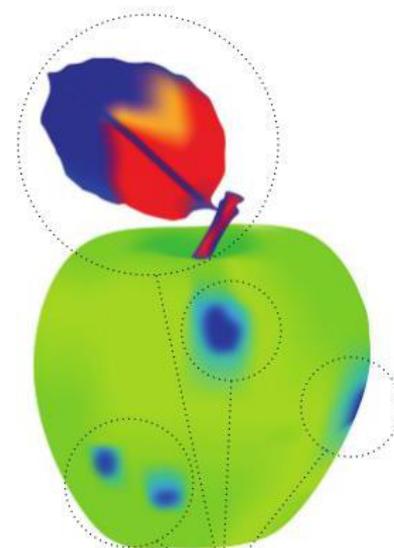
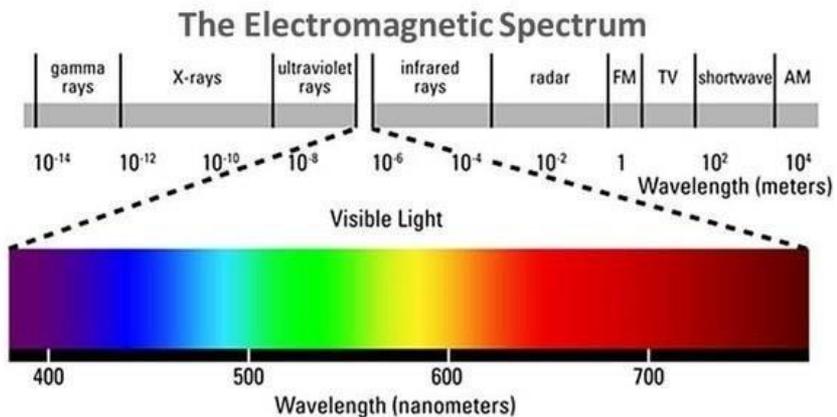
단색 영상



컬러 영상

개요

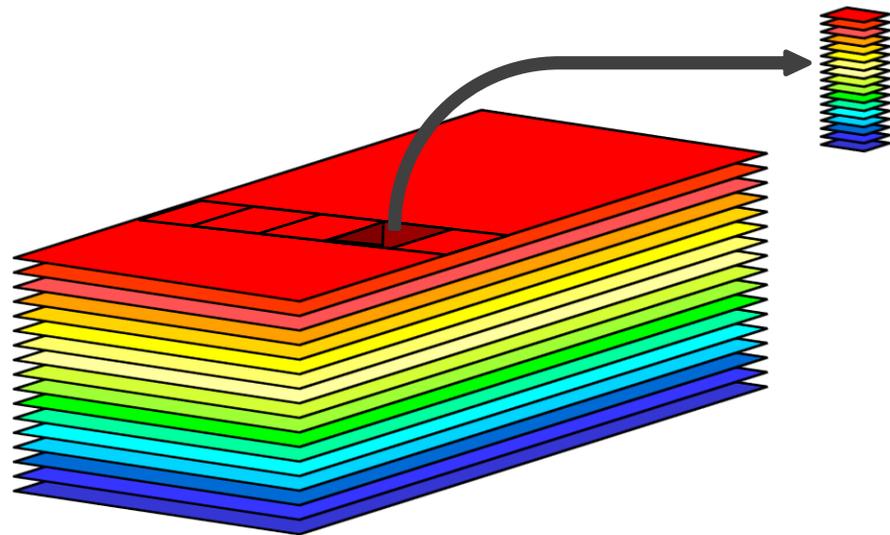
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초분광 영상

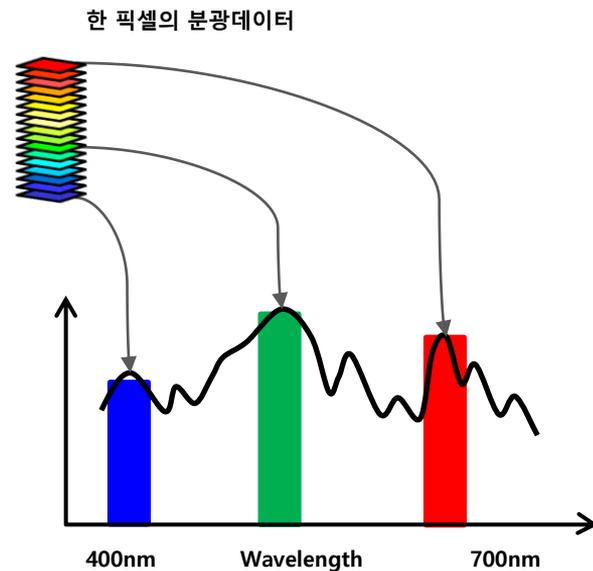
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- 스펙트럼 정보가 포함된 이미지
- 이미지의 각 픽셀당 수십 ~ 수백 개의 분광 데이터 포함



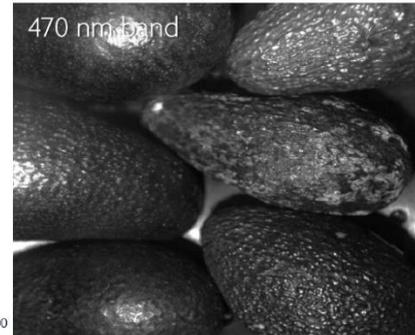
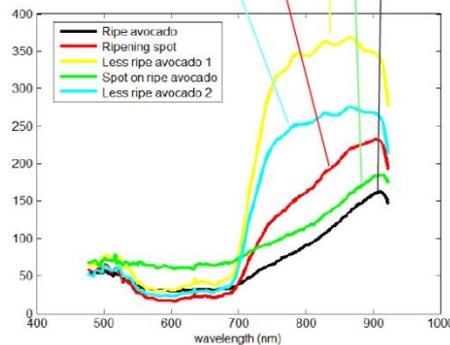
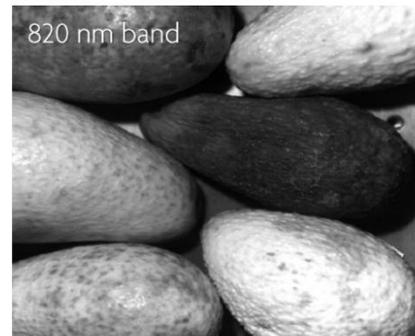
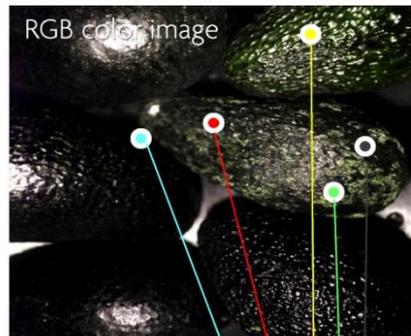
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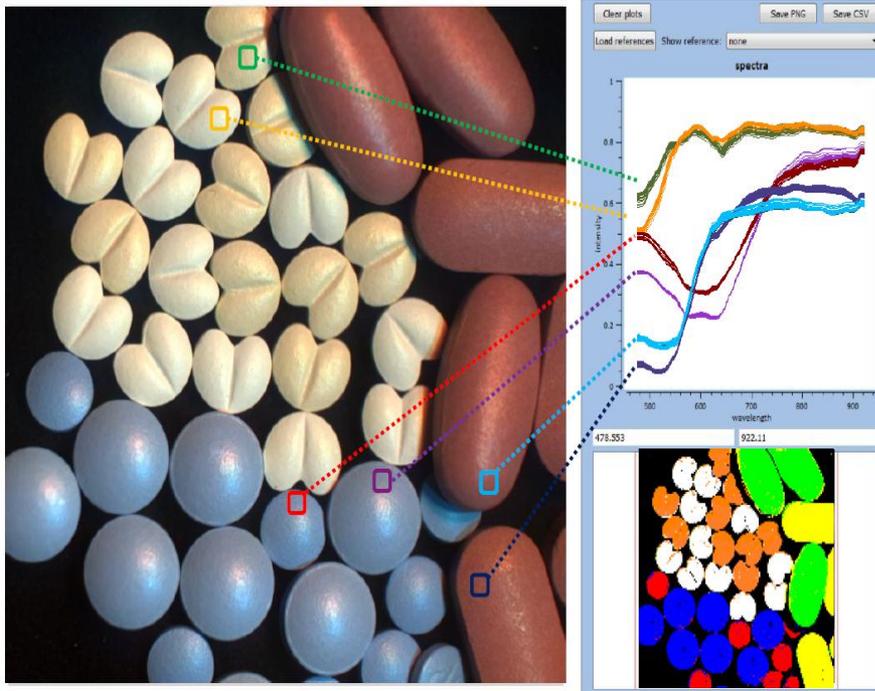
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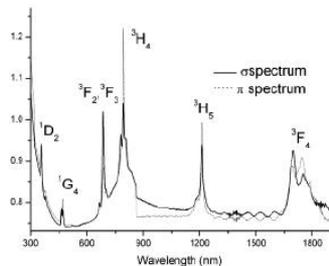
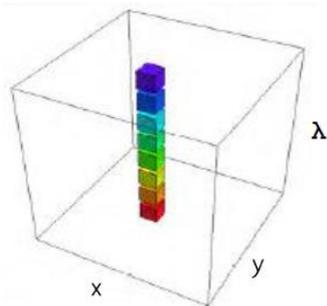
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Processed high resolution hyperspectral image:
- Background information suppressed
- Spectral anomaly isolated and amplified
- Camouflage target isolated from background
- Positive target ID

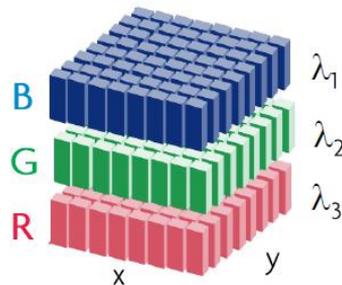
데이터 구조

분광기



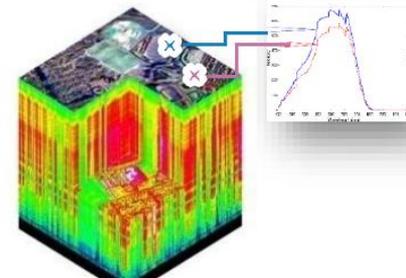
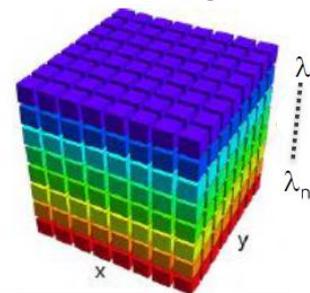
- 연속 스펙트럼 데이터
- 한 개의 측정 포인트에서만 데이터 취득

컬러 영상



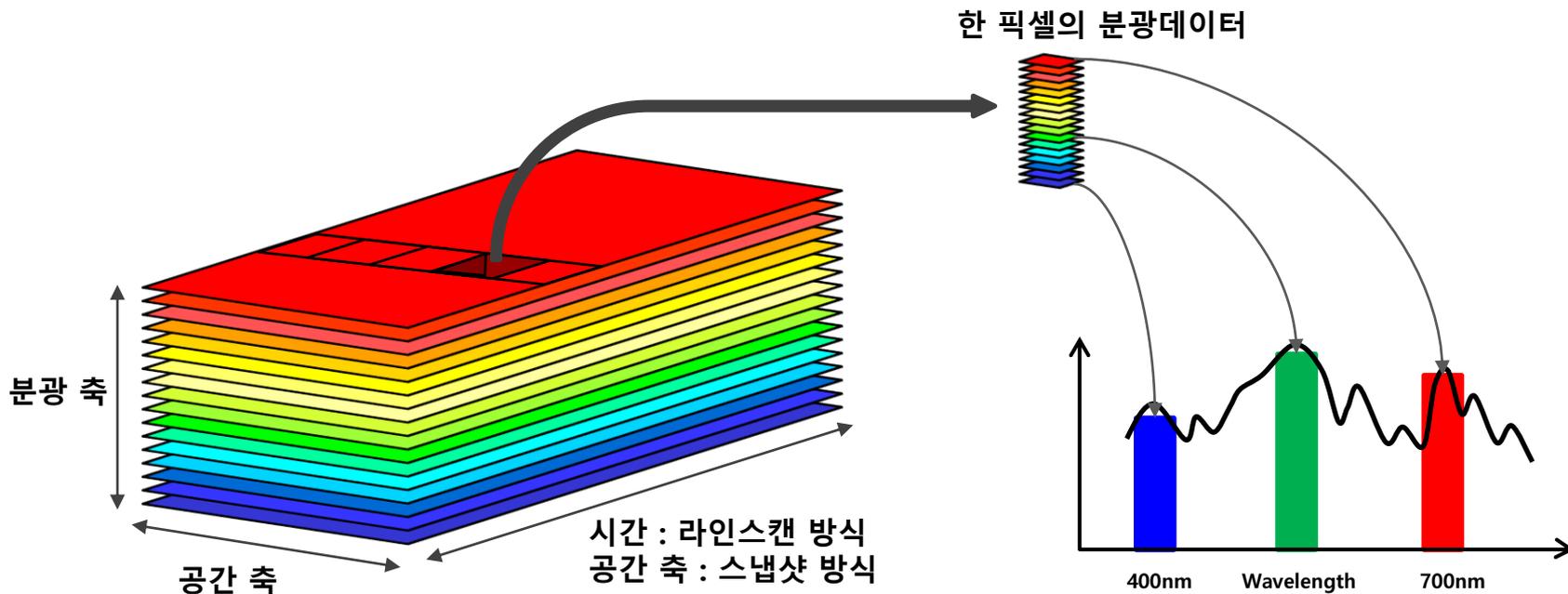
- RGB로 구성된 컬러 영상
- 시각곡선과 유사한 RGB 밴드

초분광 영상

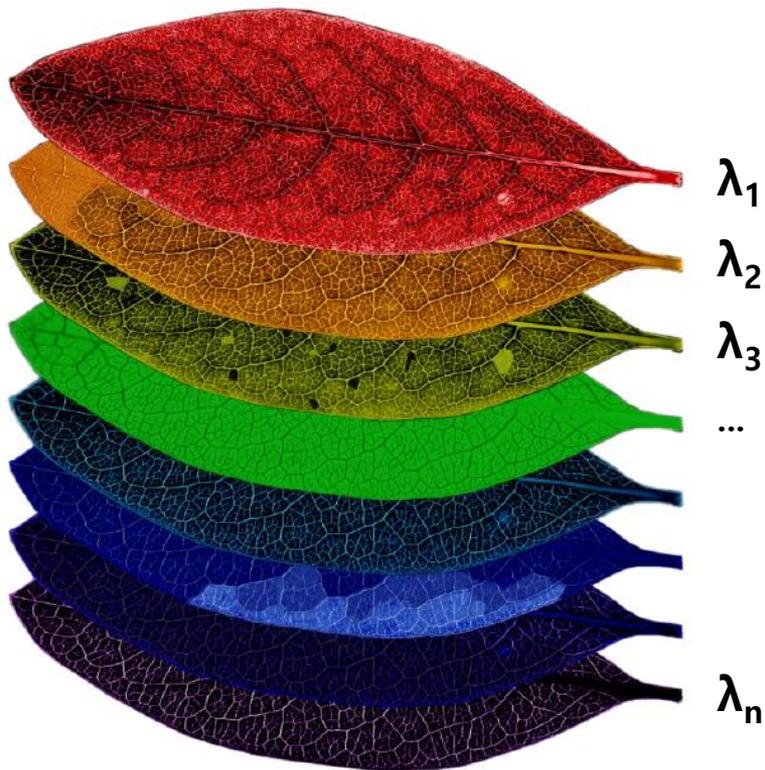


- 이미지와 분광정보가 포함된 데이터 큐브
- 대상물의 특성을 나타낼 수 있는 이미지

데이터 구조



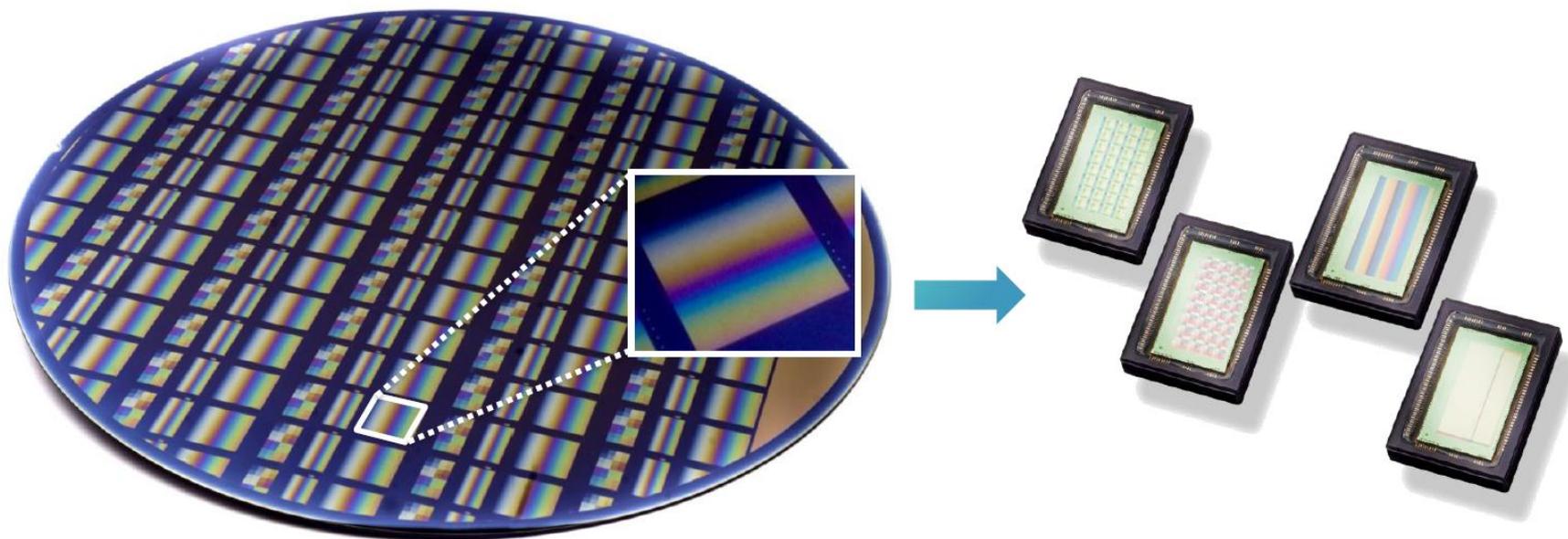
데이터 구조



- 적절한 분광 밴드의 조합으로 시각화 구현
- 촬영된 이미지의 분광축 (spectral axis)에 해당하는 데이터를 활용하여 대상물 분석
- 이미지 비교, 밴드 연산, 관심 영역 분류 등 다양한 알고리즘을 이용한 이미지 분석

초분광 센서 / Filter-based

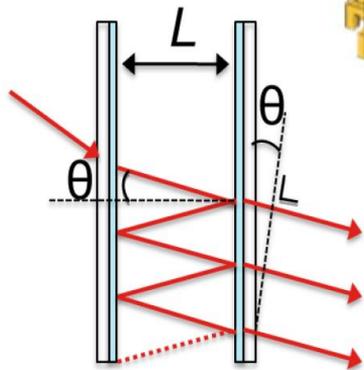
- 반도체 공정을 활용한 filter patterned on chip 구조



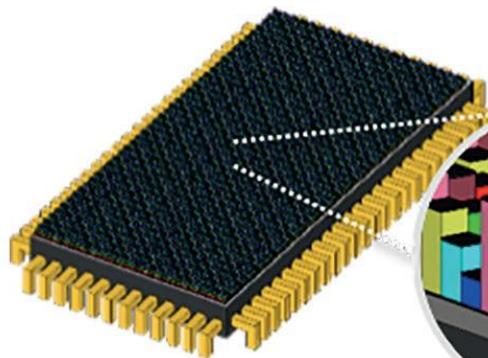
초분광 센서 / Filter-based

- 물리적인 필터 및 광학계 없이 분광영상 취득

Fabry-Pérot structures



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

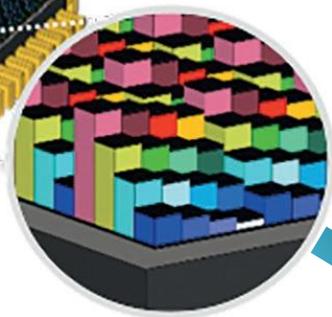


QE

10
5
0

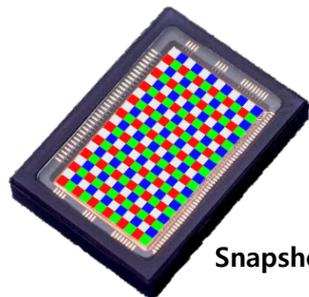
Wavelength (nm)

600 650 700 750 800 850 900 950 1000

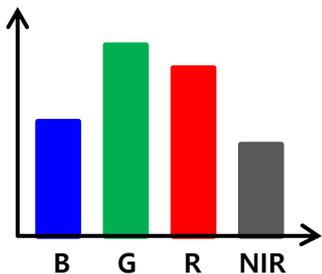


초분광 센서 / Filter-based

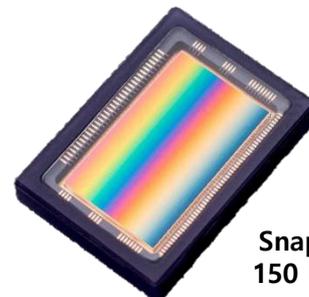
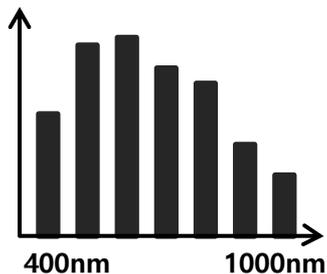
- 컴팩트한 구조의 하드웨어 구성



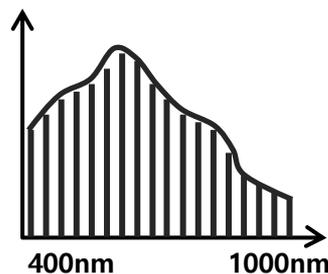
Snapshot 4 bands



Snapshot mosaic
16 / 25 bands



Snapscan
150 bands

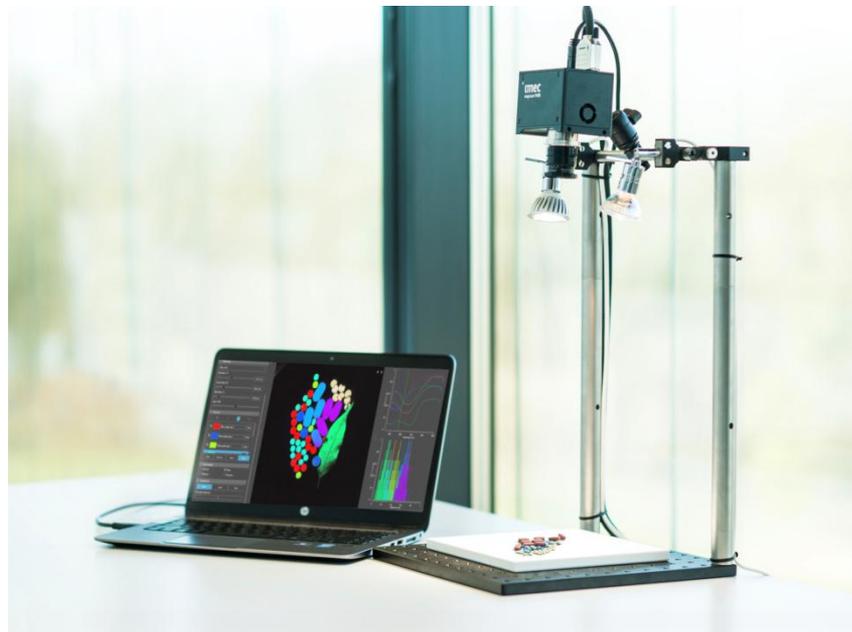


초분광 센서 / Filter-based

Sanshot Hyperspectral Camera
VIS / NIR

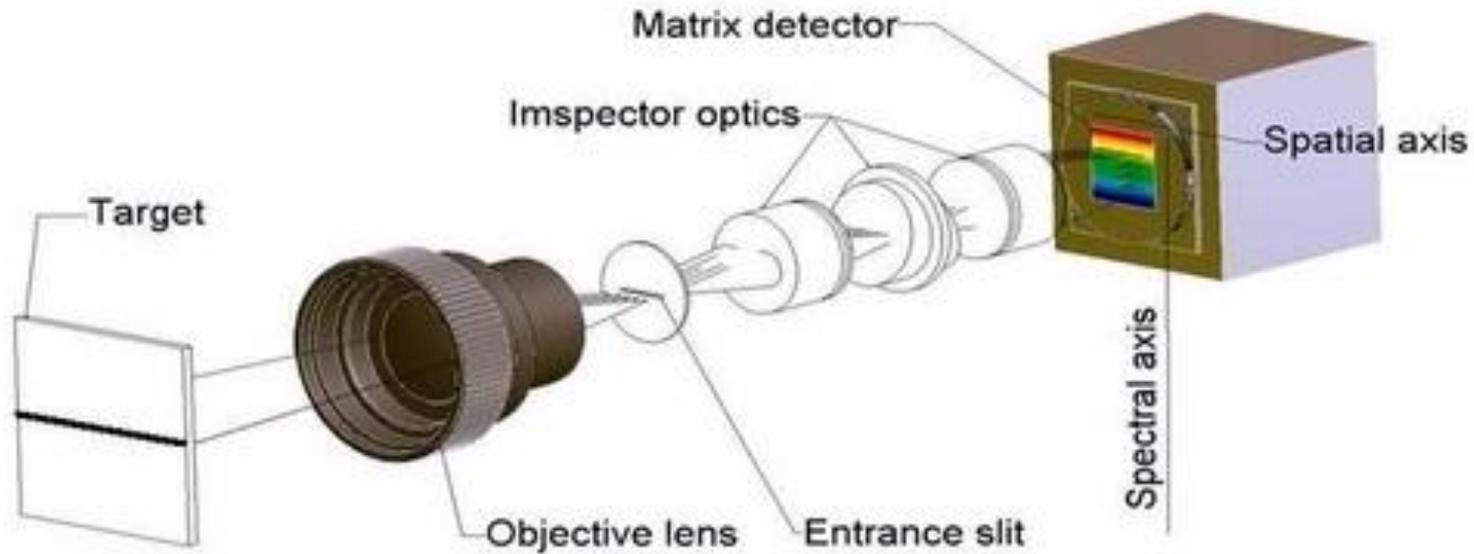


SNAPSCAN Hyperspectral Camera
VNIR



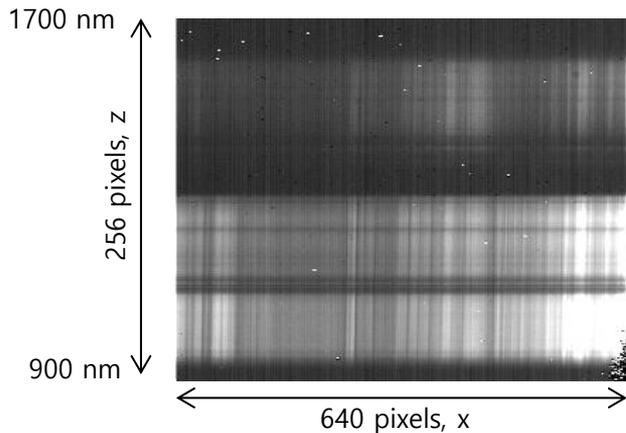
초분광 센서 / Optic-based

- 투과형 분광광학계



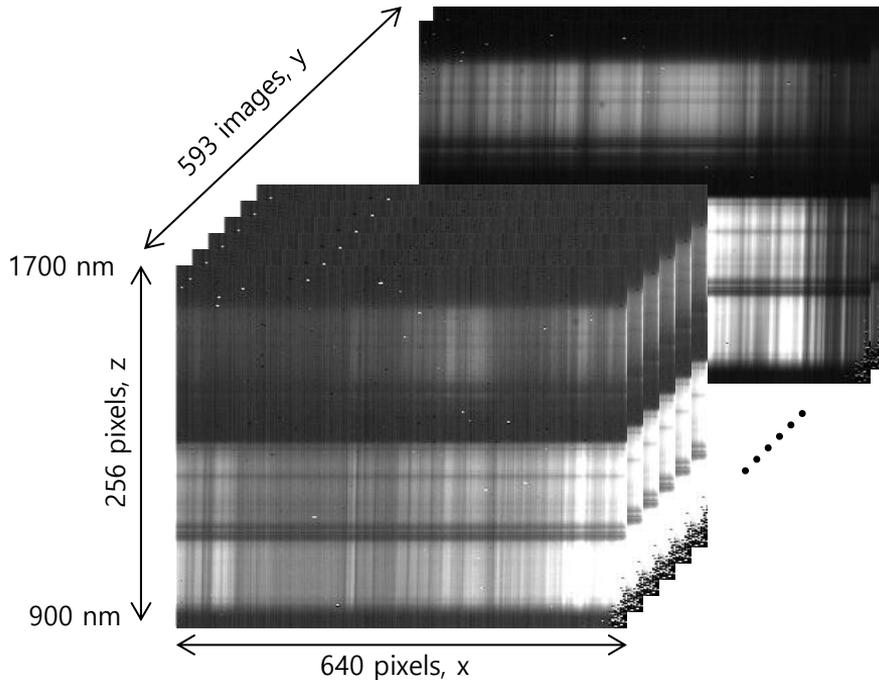
초분광 센서 / Optic-based

- 라인스캔(Push-broom) 방식으로 분광영상 취득



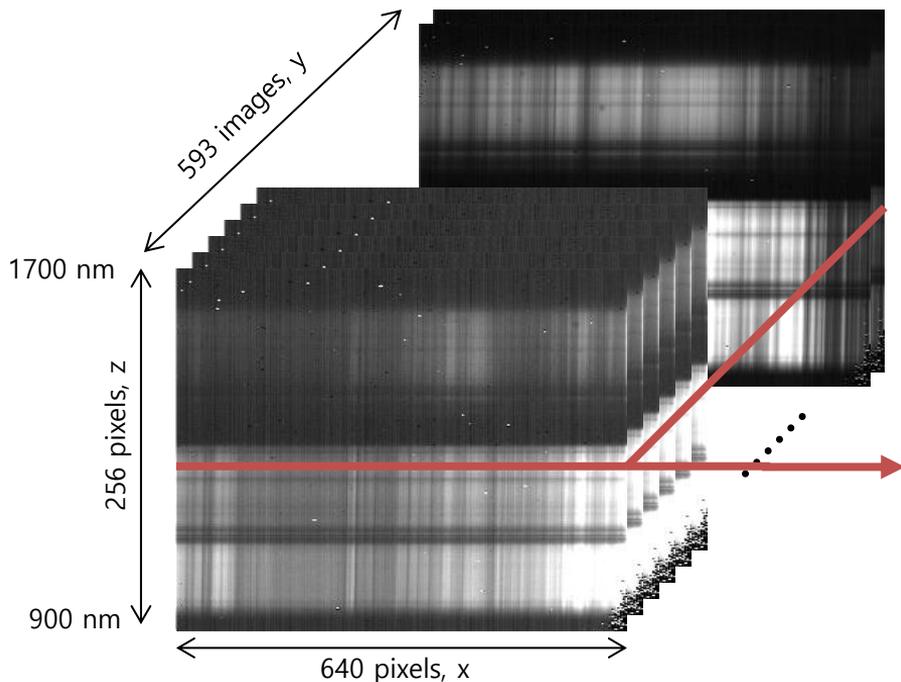
초분광 센서 / Optic-based

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초분광 센서 / Optic-based

- 라인스캔(Push-broom) 방식으로 분광영상 취득



Visualization in 1290 nm

초분광 센서 / Optic-based

Imaging Spectrograph (Standard Type)
 VIS / VNIR



Imaging Spectrograph (Enhanced Type)
 VNIR / NIR



초분광 센서 / Optic-based

Linescan Hyperspectral Camera
FX series VNIR / NIR / MWIR



Linescan Hyperspectral Camera
SWIR



초분광 센서 / Optic-based

Push-broom Scanner
Desktop



Push-broom Scanner
Customized



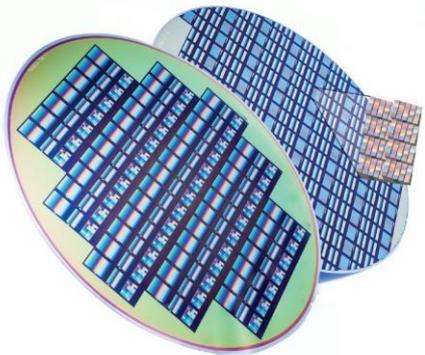
2. 초분광 카메라

Camera types

- Snapshot – 스냅샷
- Snapscan – 스냅샷 + 라인스캔
- Linescan – 라인스캔
- Mobile – 휴대형
- Drone – 드론 시스템

Snapshot Spectral Camera

- 반도체 공정을 활용한 filter patterned on chip 초분광 센서
- One-shot 촬영 방식
- 가볍고 컴팩트한 구조



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Snapshot – VIS / NIR

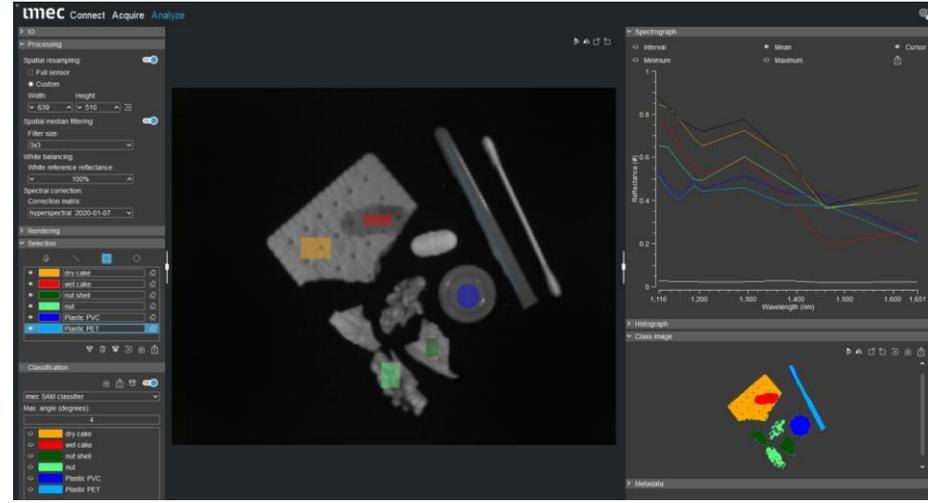


	Snapshot VIS	Snapshot NIR
공간 해상도	2048 x 1088 픽셀 (after reconstruction)	
분광 밴드	16 밴드	25 밴드
파장 범위	460 ~ 600nm	665 ~ 960nm
FWHM	< 15nm collimated	< 15nm collimated
측정 속도	최대 120 hyperspectral cubes/sec	
Bit depth	10 bit	
수광부	16 / 25 / 35 / 50mm, F2.0, C마운트	
광학 보정	Software corrected	
통신 인터페이스	USB3.0 + GPIO	
크기(mm)	31(L) x 26(W) x 26(H)	31(L) x 26(W) x 26(H)
무게	32g (렌즈 제외시)	32g (렌즈 제외시)

Snapshot – HSI Mosaic software



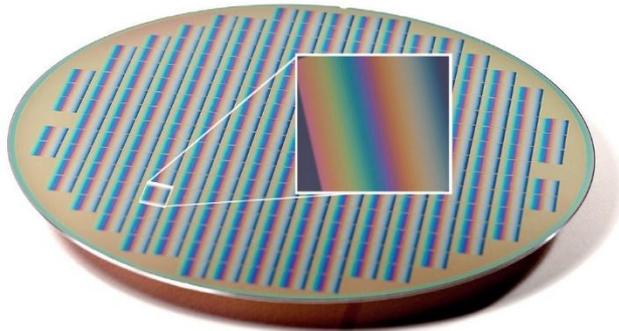
Single band images



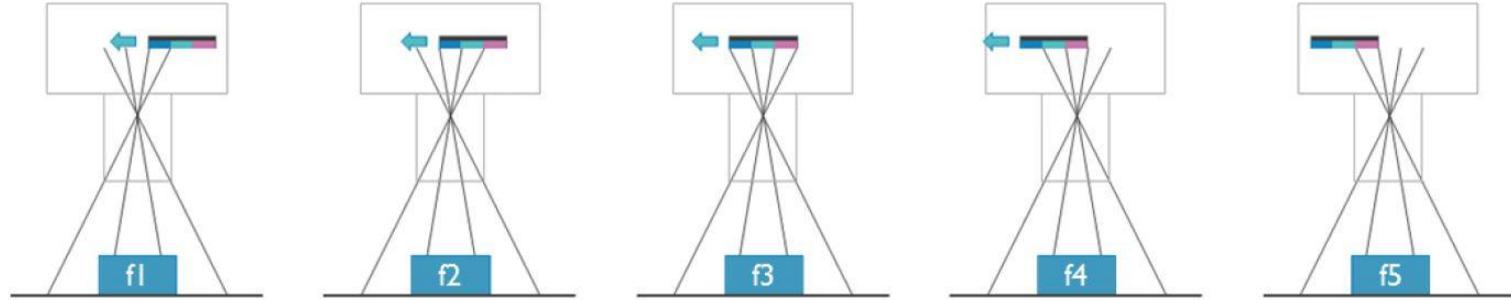
SAM classification

Snapscan Hyperspectral Camera

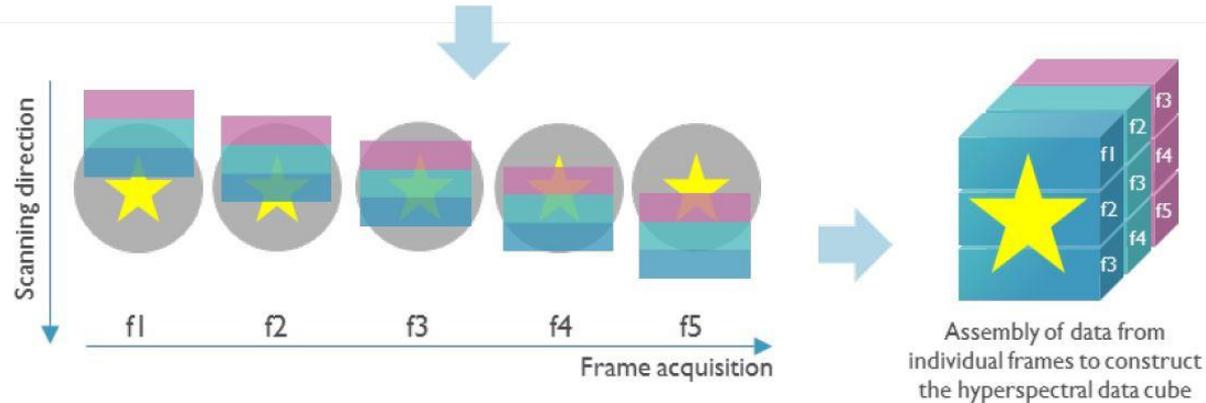
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- 내부 스캔 촬영 방식
- 고해상도의 full spectrum 이미지



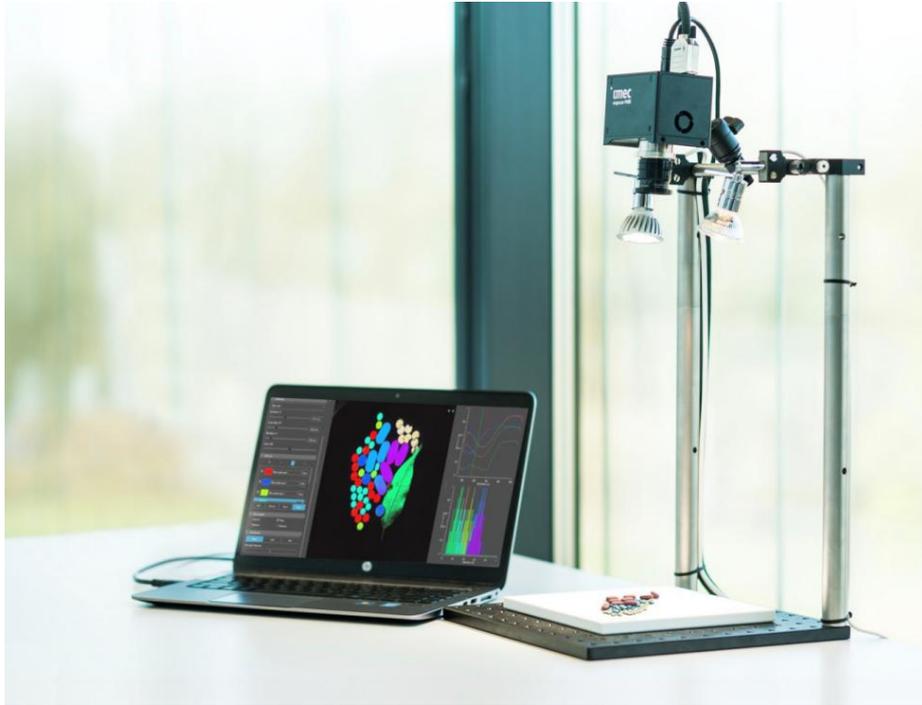
Snapscan Hyperspectral Camera



Both the object and the camera remain stationary. The sensor inside the camera moves to acquire the complete hyperspectral data.

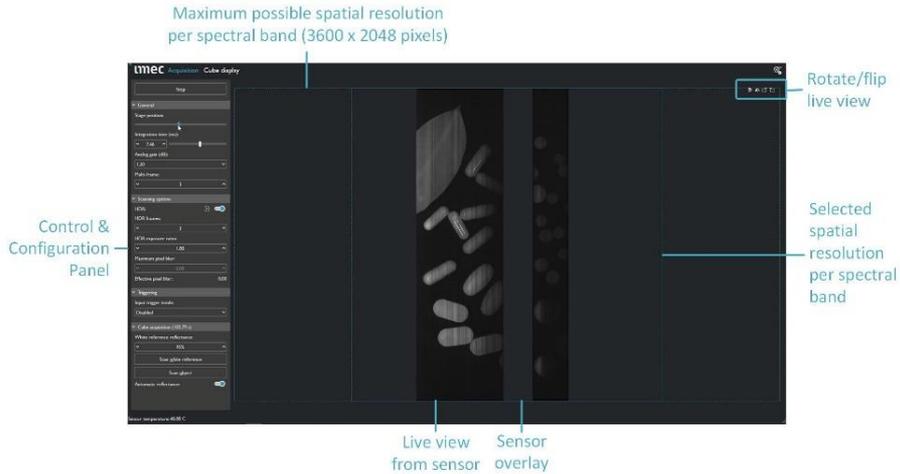


Snapscan – VNIR



SNAPSCAN VNIR	
공간 해상도	최대 3600 x 2048 픽셀
분광 밴드	150 밴드
파장 범위	470 ~ 900nm
FWHM	< 10 ~ 15nm
측정 속도	2s ~ 20s (depends on acquisition parameters)
스캔 시스템	내장형 piezo scanning platform
Bit depth	10 bit
수광부	20 / 24 / 35 / 50mm, F2.0, C마운트
냉각 방식	fan based + TE cooling electronics
셔터	자동 영점 조정을 위한 기계식 셔터 내장
SNR	> 100 ~ 200
통신 인터페이스	USB3.0 + GPIO
크기(mm)	100(L) x 70(W) x 70(H)
무게	645g (렌즈 제외시)

Snapscan – HSI Snapscan software



Live view display for acquisition mode

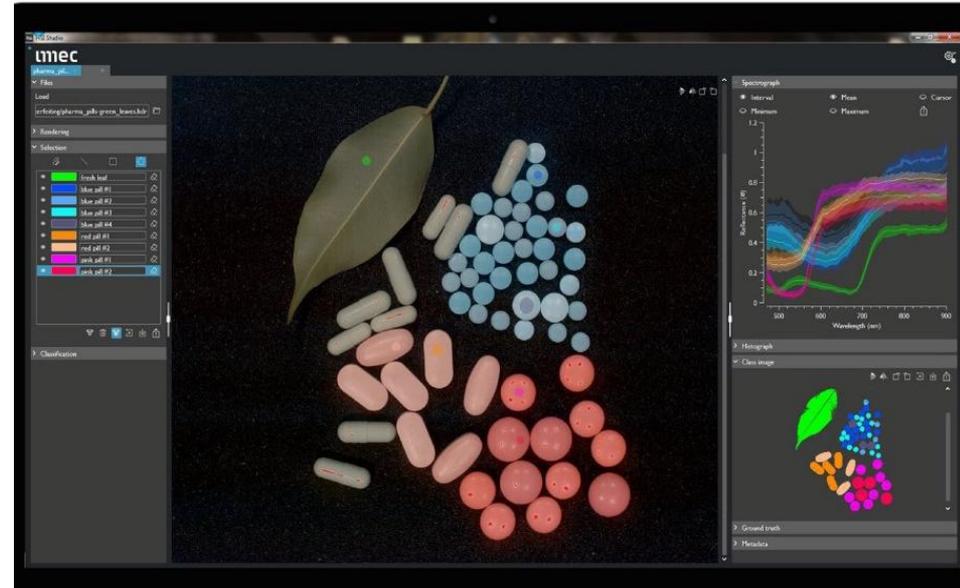
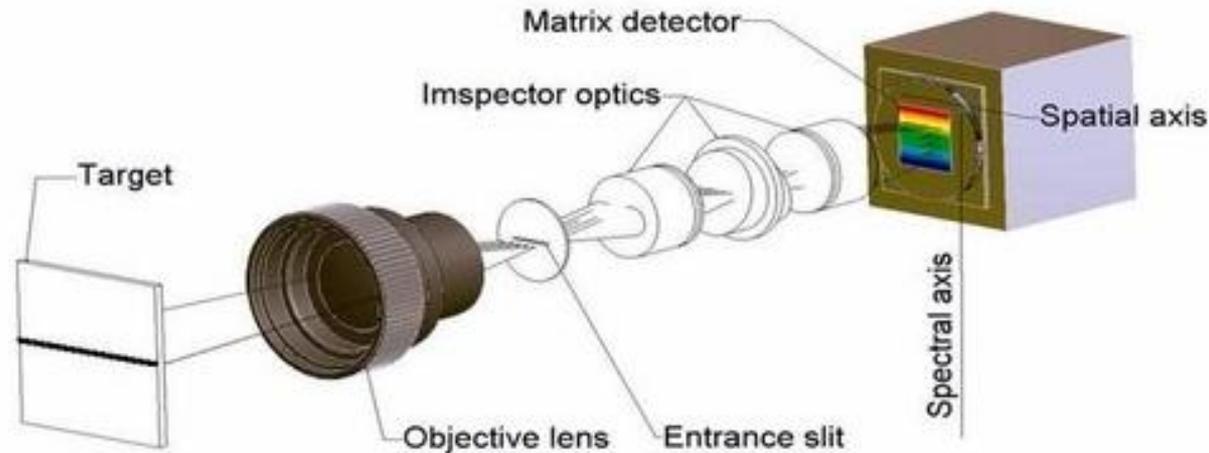


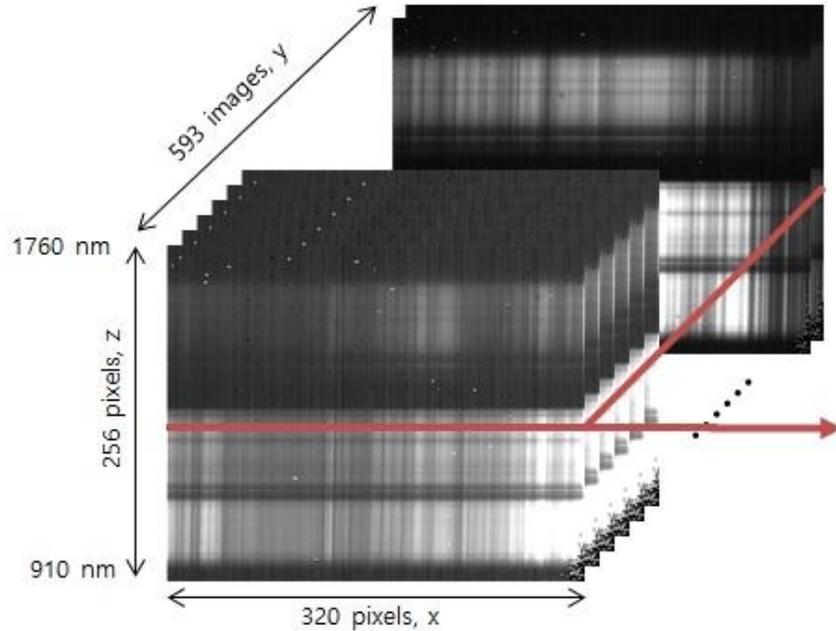
Image analysis and classification in cube display mode

Linescan Hyperspectral Camera

- 투과형 분광 광학계
- 라인 스캔 촬영 방식
- 고해상도의 full spectrum 이미지



Linescan Hyperspectral Camera



Visualization in 1290 nm

Linescan Hyperspectral Camera



Linescan – FX10



Spectral Range	400-1000 / 400-770 (c-version)
Spectral resolution (FWHM)	5.5 nm (mean)
Spectral sampling/pixel	2.7 nm
Spectral bands	224 / 140 (c-version)
Numerical aperture	1.7
Optics magnification	0.80
Effective pixel size	19.9x9.97 μm
Effective slit width	42 μm
Effective slit length	10.2 mm
SNR @ max. signal	420 : 1
Spatial samples	1024
Bit depth	12
Maximum frame rate	327 FPS full range / 514 FPS full range (c-version)
Dimensions (L x W x H)	150 x 85 x 71 mm
Weight	1.3 kg
Storage temperature	-20 ... +50°C (non-condensing)

Linescan – FX17



Spectral Range	900-1700 nm
Spectral resolution (FWHM)	8 nm (mean)
Spectral sampling/pixel	3.5 nm
Spectral bands	224
Numerical aperture	1.7
Optics magnification	0.80
Effective pixel size	18.7 μm
Effective slit width	Physical width 42 μm . Projection on sensor 32 μm (M=1.3)
Effective slit length	12.0 mm
SNR @ max. signal	1000:1
Bit depth	12
Maximum frame rate	670 (FX17) 527 (FX17e) FPS full range
Dimensions (L x W x H)	150 x 75 x 85 mm
Weight	1.56 kg
Storage temperature	-20 ... +50 °C (non-condensing)

Linescan – FX50



Spectral Range	2.7 - 5.3 μm
Spectral resolution (FWHM)	35 nm
Spectral sampling/pixel	8.44 nm
Spectral bands	154
Numerical aperture	2.0
Optics magnification	0.5
Effective pixel size	30 μm
Effective slit width	104 μm
Effective slit length	19.2 mm
Dynamic Range	2000:1 (1.5ms); 5000:1 (0.2ms)
Max SNR	1300:1 (1.5ms); 1800:1 (0.2ms)
Spatial samples	640
Bit depth	16
Maximum frame rate	377 fps
Dimensions (L x W x H)	280 x 202 x 161 mm
Weight	7.0 kg

Linescan – FX120



Spectral Range	7.7 - 12.3 μm
Spectral resolution (FWHM)	100 nm
Spectral sampling/pixel	30 nm
Spectral bands	160
Numerical aperture	2.0
Optics magnification	0.5
Effective pixel size	30 μm
Effective slit width	104 μm
Effective slit length	18.5 mm
Dynamic Range - Reflectance measurement	4000:1 (1.5ms); 6000:1 (0.2ms)
Max SNR - Reflectance measurement	2500:1 (1.5ms) ; 3000:1 (0.2ms)
Max SNR - Emission measurement	500
Spatial pixels	616
Bit depth	16
Maximum frame rate	240 FPS
Dimensions (L x W x H)	250 mm x 300 mm x 220 mm
Weight	15 kg

Linescan – SWIR



OPTICAL CHARACTERISTICS

Spectral range	1000 - 2500 nm
Spectral resolution (FWHM)	12 nm (30 µm slit)
Spectral sampling / pixel	5.6 nm
F/#	F/2.0
Slit width	30 µm (50 or 80 µm optional)
Effective slit length	9.2 mm

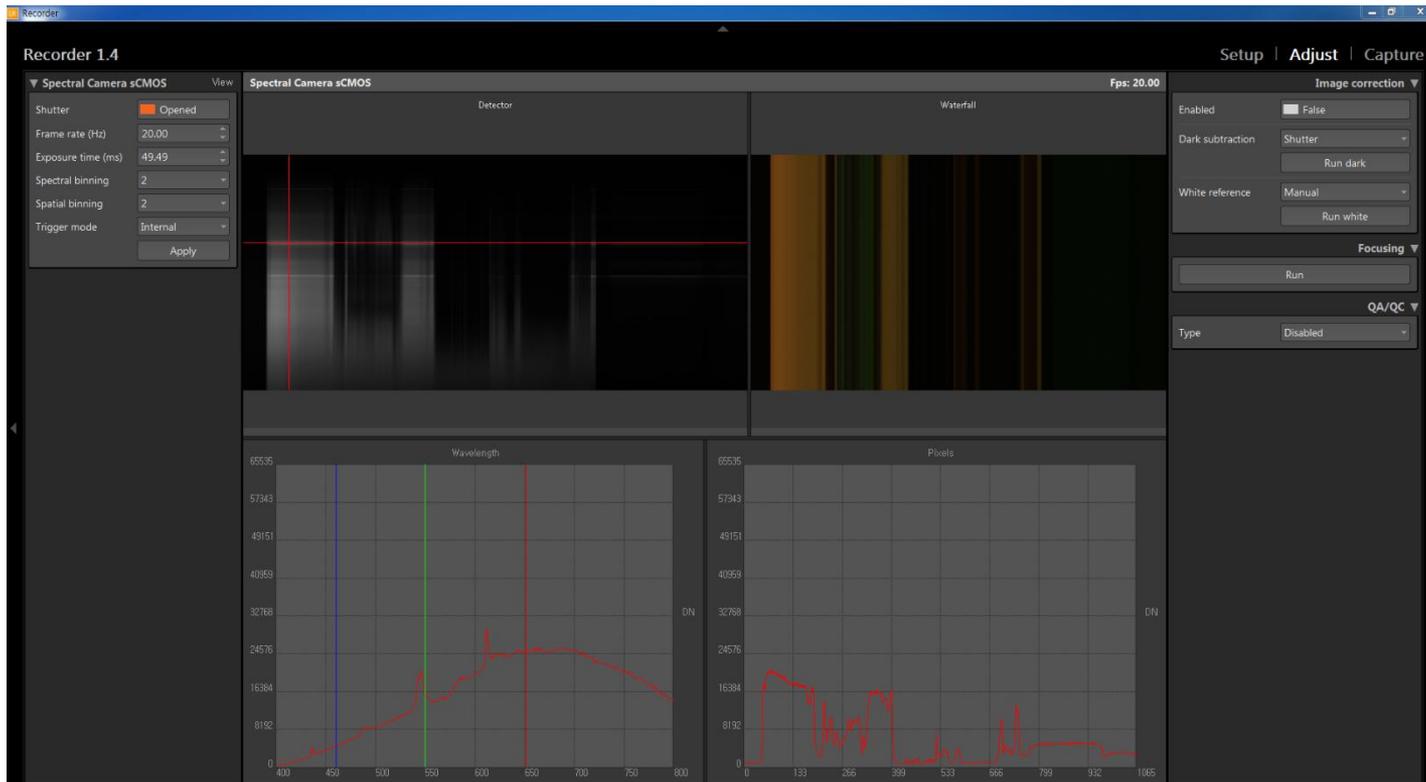
ELECTRICAL CHARACTERISTICS

Sensor	Cryogenically cooled MCT detector
Spatial pixels	384
Spectral bands	288
Pixel size	24 x 24 µm
Detector cooling	Stirling, 25 000 h MTF
Signal-to-noise ratio	1050:1 (at max. signal level)
Camera output	16 bit CameraLink

MECHANICAL CHARACTERISTICS

Size (L x W x H)	Sensor 545 x 176 x 178 mm, PSU & control unit 300 x 190 x 130 mm
Weight	14 kg & approx. 5 kg
Body	Anodized aluminium with mounting screwholes
Lens mount	Standard C-mount
Shutter	Electro-mechanical

Linescan – LUMO data acquisition software



Mobile Hyperspectral Camera

- 디지털 카메라 방식의 휴대형 초분광 카메라
- 측정에서 분석까지 자율적 운용 가능
- 내장 GPS를 활용한 측정데이터의 위치정보 기록
- USB연결 또는 WIFI를 통신을 이용한 원격 제어



Mobile Hyperspectral Camera



Feature	Value
Spectral camera	VNIR 400~1000 nm (CMOS)
Viewfinder camera	5 Mpix
User interface SW	By Specim
Storage	SD card max 32 GB
Data Format	Specim Dataset with ENVI compatible data files
Battery	5200 mAh Li-Ion (Type 26650)
Operational time	Appx. 100 measurements with one SD card and battery
Display & keyboard	4.3" touch screen + 13 physical buttons
Camera interface	USB Type-C
Size	207 x 91 x 74 mm (depth with lens 125,5 mm)
Weight	1.3 kg
F/number	1.7
Wavelength band	400~1000 nm
Spectral resolution FWHM	7 nm
Spatial Sampling	512 pix
Spectral bands	204

Drone Hyperspectral Camera – Linescan

- Push-broom 방식
- GPS/IMU 통합형 센서
- 다양한 플랫폼 호환

항목	특징
Sensor Type	Push-broom Line Imaging Spectrometer
Detector Type	CCD/CMOS hybrid 1408 spatial pixels
Focal Length / FOV	16mm / 29.5degrees
Spectral Range	400 ~ 1,000nm
Spectral Bands	155 bands (2bin)
Spatial Pixels	704 pixels (2bin)
INS	GPS + Mems IMU
Size / Weight	13.7 x 8.8 x 7.1cm / 680g



3. 국내외 활용 사례

농업 – Farm Mapping

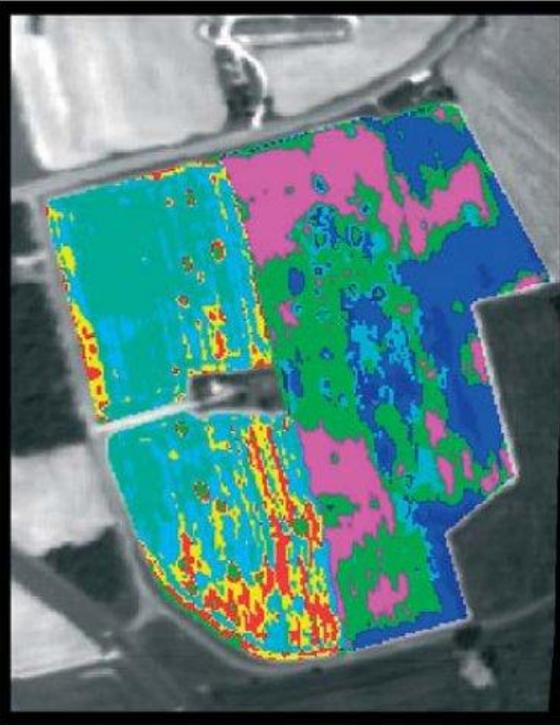


Figure 1. Unsupervised classification

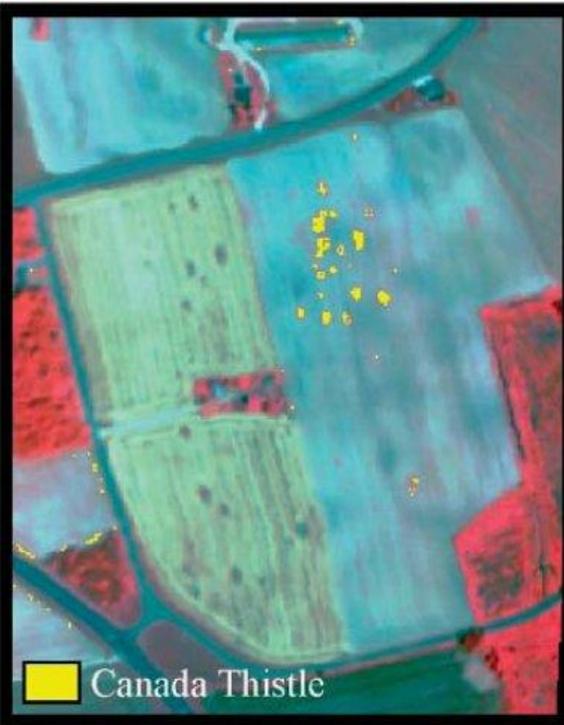


Figure 2. Supervised classification

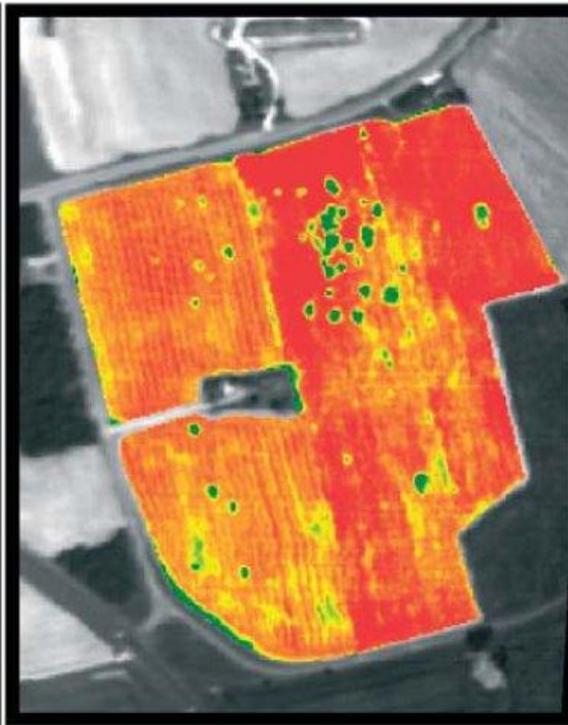
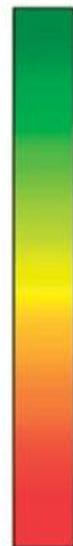


Figure 3. Relative biomass

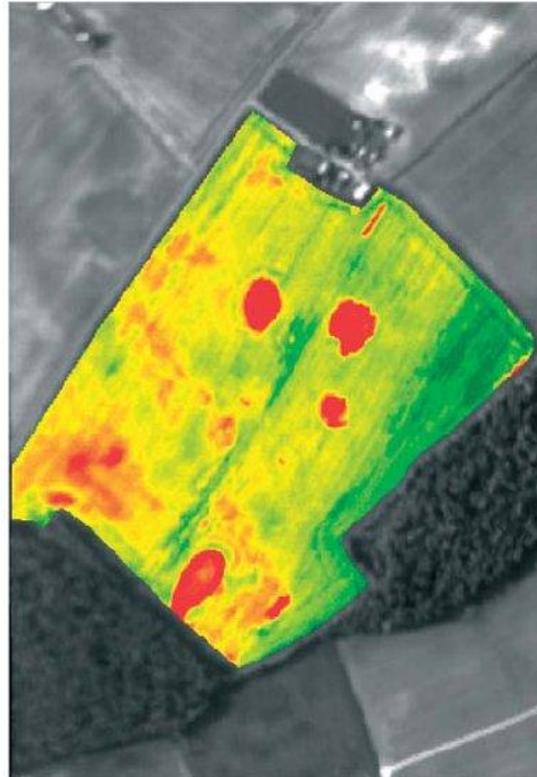
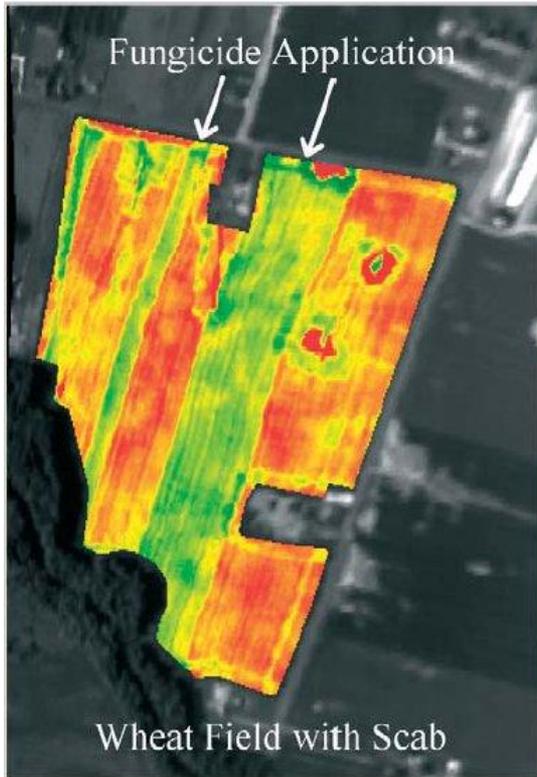
High



Low

이종 농작물 식별

농업 – Biomass Mapping



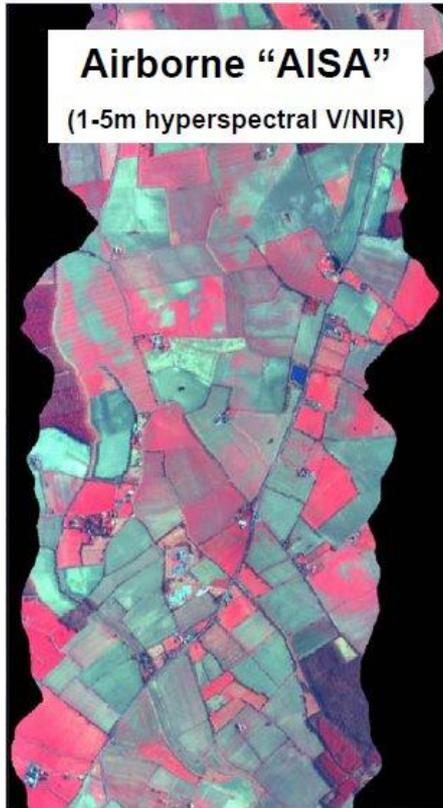
High



Low

녹색 영역 : 살충제 살포 후 농작물의 호전된 상태를 표현

농업 – Precision Farming



ISOCROP 2002		Winter wheat
Leaf Chlorophyll Content		
Field : Bodegas El Soto		
Area : 0.00 ha		
Variety : INCONNU		
Drilling date :		

FARMSTAR	
Leaf Area Index	
Variable Scale	
ISOCROP	
Field: 46 ACRE (P1)	
Area: 18.06 ha	Drilling date: 13/09/2002
Variety: CONSORT	Drilling density: 160

	Area (ha)
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0

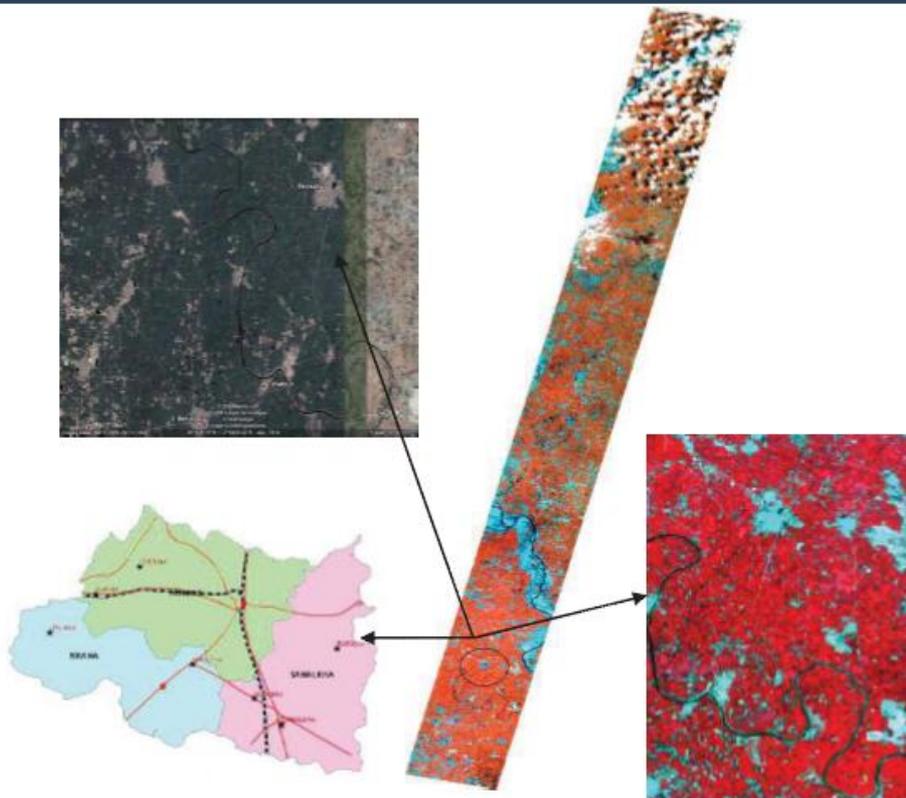
FARMSTAR		Winter Wheat Package												
Lodging Risk														
GS30/GS32														
Field: Date														
Area: 12.5 ha	Drilling date: 25/09/2003													
Variety: Clare	Drilling density: 225													
Lodging risk map														
Interpretation date: 04/05/2004														
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th style="width: 30px;">Risk level</th> <th style="width: 30px;">% Area</th> <th style="width: 30px;">Area (ha)</th> </tr> <tr> <td style="text-align: center;">Low</td> <td style="text-align: center;">43.4</td> <td style="text-align: center;">5.4</td> </tr> <tr> <td style="text-align: center;">Medium</td> <td style="text-align: center;">17.0</td> <td style="text-align: center;">2.1</td> </tr> <tr> <td style="text-align: center;">High</td> <td style="text-align: center;">39.7</td> <td style="text-align: center;">5.0</td> </tr> </table>	Risk level	% Area	Area (ha)	Low	43.4	5.4	Medium	17.0	2.1	High	39.7	5.0		
Risk level	% Area	Area (ha)												
Low	43.4	5.4												
Medium	17.0	2.1												
High	39.7	5.0												
<ol style="list-style-type: none"> 1. Low risk - Early season growth regulator applications should provide sufficient lodging control. 2. Medium risk - Early season growth regulator applications should provide sufficient lodging control unless specific field conditions (eg field aspect and exposure) raise the risk level - discuss with agronomist. 3. High risk - A further growth regulator application is recommended - consult agronomist. 														
i Next stage: Flag leaf just visible by the 12/05/2004														

	Area (ha)
1.0	1.0
1.8	1.8
2.3	2.3
8.1	8.1
3.5	3.5
0.3	0.3
0.0	0.0

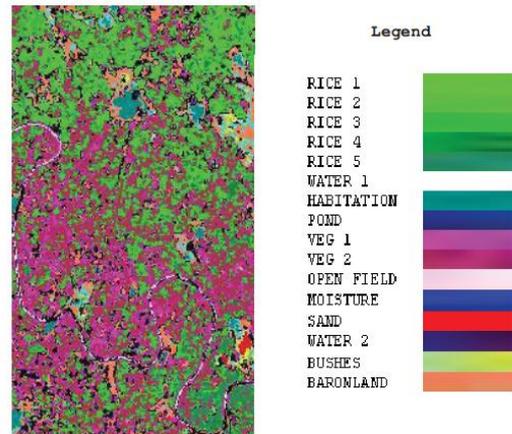
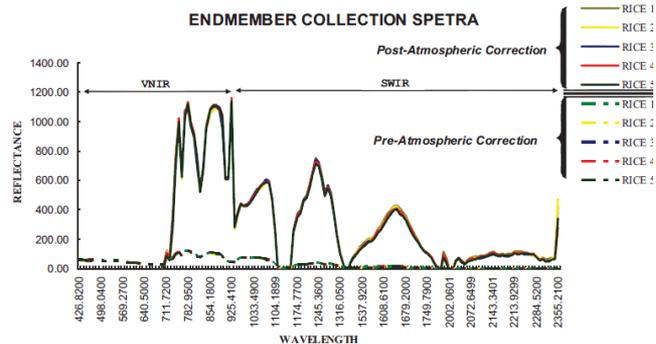
항공용 초분광 카메라 취득 영상

작물 상태, 재배 면적, 수확량 및 수확 시기 예측

농업 - 농작물 분류



벼 품종에 대한 분광 라이브러리 구축



SAM(Spectral Angle Mapper) 분류 이미지

농업 - 병충해 모니터링



Figure 1. Leaf infected with citrus canker.



Figure 2. Ground view of a test site.



Figure 3. Aircraft used for citrus canker project.



Figure 4. Aerial photo of citrus grove from 3,000 feet.

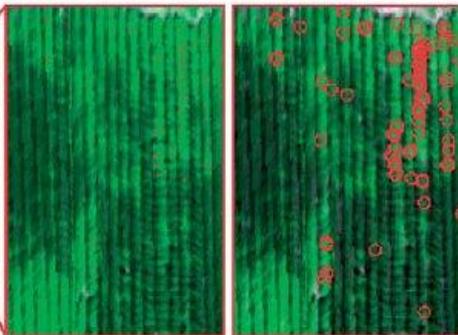
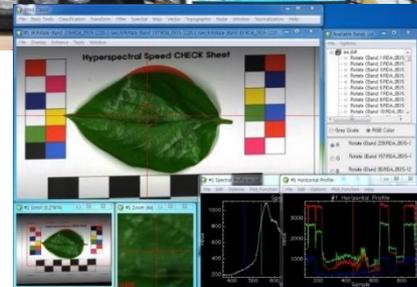
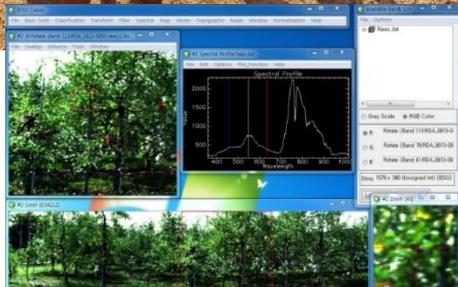


Figure 5. Hyperspectral image processed to highlight citrus canker infestations in red.



Figure 6. Sample cube.

농업 - 병충해 조기 탐지



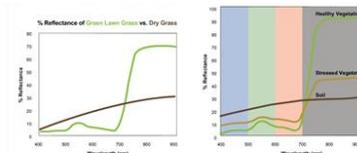
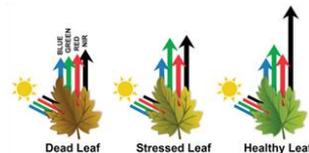
사과나무 갈색무늬 마름병 - 국립농업과학원 현장 촬영

과실 및 잎 촬영을 위한 실험실용 암실 시스템

농업 - 식생 지수(Vegetation Index)

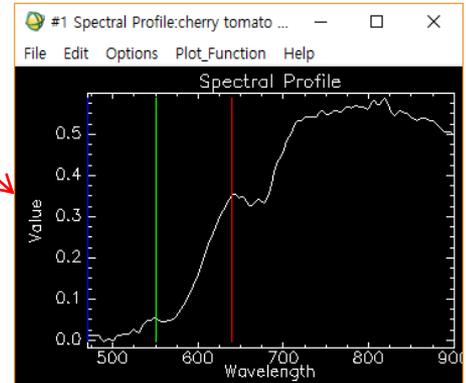
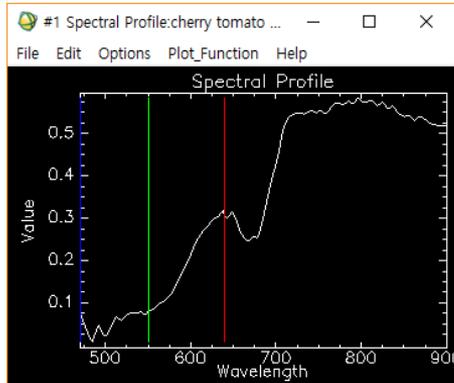
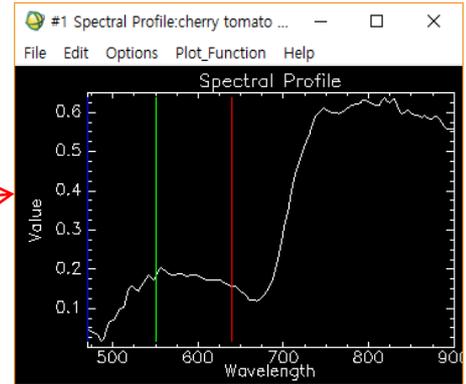
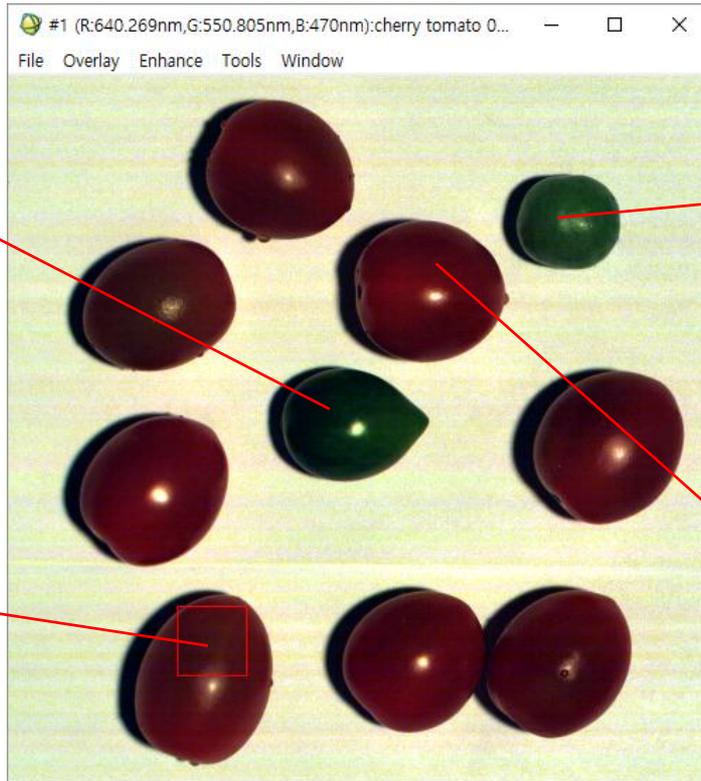
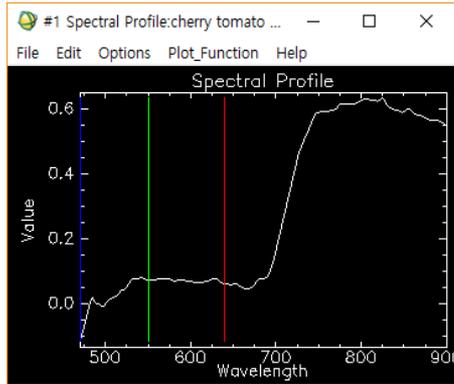
No.	식생 리스트	수식
1	Normalized Difference Vegetation Index (NDVI)	$NDVI = \frac{\rho_{865} - \rho_{670}}{\rho_{865} + \rho_{670}}$
2	Enhanced Vegetation Index (EVI)	$EVI = 2.5 \cdot \frac{(NIR - Red)}{(NIR + 6 \cdot Red - 7.5 \cdot Blue + 1)}$
3	Leaf Area Index (LAI)	$LAI = (3.618 \cdot EVI - 0.118)$
4	Atmospherically Resistant Vegetation Index (ARVI)	$ARVI = \frac{\rho_{865} - [\rho_{680} - \gamma(\rho_{680} - \rho_{660})]}{\rho_{865} + [\rho_{680} - \gamma(\rho_{680} - \rho_{660})]}$
5	Modified Chlorophyll Absorption Ratio Index (MCARI)	$MCARI = \{(\rho_{700} - \rho_{670}) - 0.2(\rho_{700} - \rho_{550})\} \cdot (\rho_{700} / \rho_{670})$
6	Modified Chlorophyll Absorption Ratio Index Improved (MCARI2)	$MCARI2 = \frac{1.5[2(\rho_{680} - \rho_{670}) - 1.3(\rho_{680} - \rho_{550})]}{\sqrt{(2 \cdot \rho_{680} + 1)^2 - (6 \cdot \rho_{680} - 5 \cdot \sqrt{\rho_{670}}) - 0.5}}$
7	Modified Red Edge Normalized Difference Vegetation Index (MRENDVI)	$MRENDVI = \frac{\rho_{750} - \rho_{670}}{\rho_{750} + \rho_{670} - 2 \cdot \rho_{645}}$
8	Modified Red Edge Simple Ratio (MRESR)	$MRESR = \frac{\rho_{750} - \rho_{645}}{\rho_{750} + \rho_{645}}$
9	Modified Triangular Vegetation Index (MTVI)	$MTVI = 1.2[1.2(\rho_{865} - \rho_{550}) - 2.5(\rho_{670} - \rho_{550})]$
10	Modified Triangular Vegetation Index - Improved (MTVI2)	$MTVI2 = \frac{1.5[1.2(\rho_{865} - \rho_{550}) - 2.5(\rho_{670} - \rho_{550})]}{\sqrt{(2 \cdot \rho_{865} + 1)^2 - (6 \cdot \rho_{865} - 5 \cdot \sqrt{\rho_{670}}) - 0.5}}$
11	Red Edge Normalized Difference Vegetation Index (RENDVI)	$RENDVI = \frac{\rho_{750} - \rho_{685}}{\rho_{750} + \rho_{685}}$
12	Transformed Chlorophyll Absorption Reflectance Index (TCARI)	$TCARI = 3 \left\{ (\rho_{700} - \rho_{670}) - 0.2(\rho_{700} - \rho_{550}) \left(\frac{\rho_{680}}{\rho_{670}} \right) \right\}$
13	Triangular Vegetation Index (TVI)	$TVI = \frac{120(\rho_{750} - \rho_{550}) - 200(\rho_{670} - \rho_{550})}{2}$
14	Vogelmann Red Edge Index 1 (VREI1)	$VREI1 = \frac{\rho_{740}}{\rho_{720}}$
15	Vogelmann Red Edge Index 2 (VREI2)	$VREI2 = \frac{\rho_{725} - \rho_{747}}{\rho_{715} + \rho_{726}}$
16	Normalized Difference Nitrogen Index (NDNI)	$NDNI = \frac{\log\left(\frac{1}{\rho_{310}}\right) - \log\left(\frac{1}{\rho_{865}}\right)}{\log\left(\frac{1}{\rho_{310}}\right) + \log\left(\frac{1}{\rho_{865}}\right)}$
17	Photochemical Reflectance Index (PRI)	$PRI = \frac{\rho_{435} - \rho_{570}}{\rho_{435} + \rho_{570}}$
18	Structure Insensitive Pigment Index (SIPI)	$SIPI = \frac{\rho_{680} - \rho_{445}}{\rho_{680} - \rho_{480}}$

No.	식생 리스트	수식
19	Red Green Ratio Index (RGRi)	$RGRi = \frac{\rho_{670} - R_i}{\rho_{510} - R_i} \cdot \frac{\rho_{510} - R_j}{\rho_{670} - R_j}$
20	Cellulose Absorption Index (CAI)	$CAI = 0.5(\rho_{2100} + \rho_{2200}) - \rho_{2100}$
21	Lignin Cellulose Absorption Index (LCAI)	$LCAI = 100 \cdot \left[(\rho_{2180} - \rho_{2120} - \rho_{2140} + \rho_{2160}) + (\rho_{2180} - \rho_{2120} - \rho_{2170} + \rho_{2190}) \right]$
22	Normalized Difference Lignin Index (NDLI)	$NDLI = \frac{\log\left(\frac{1}{\rho_{2174}}\right) - \log\left(\frac{1}{\rho_{2065}}\right)}{\log\left(\frac{1}{\rho_{2174}}\right) + \log\left(\frac{1}{\rho_{2065}}\right)}$
23	Plant Senescence Reflectance Index (PSRI)	$PSRI = \frac{\rho_{680} - \rho_{550}}{\rho_{550}}$
24	Anthocyanin Reflectance Index 1 (ARI1)	$ARI1 = \frac{1}{\rho_{550}} - \frac{1}{\rho_{700}}$
25	Anthocyanin Reflectance Index 2 (ARI2)	$ARI2 = \rho_{600} \left[\frac{1}{\rho_{550}} - \frac{1}{\rho_{700}} \right]$
26	Carotenoid Reflectance Index 1 (CRI1)	$CRI1 = \frac{1}{\rho_{510}} - \frac{1}{\rho_{550}}$
27	Carotenoid Reflectance Index 2 (CRI2)	$CRI2 = \frac{1}{\rho_{510}} - \frac{1}{\rho_{700}}$
28	Moisture Stress Index (MSI)	$MSI = \frac{\rho_{1600}}{\rho_{1510}}$
29	Normalized Difference Infrared Index (NDII)	$NDII = \frac{(\rho_{2130} - \rho_{1640})}{(\rho_{2130} + \rho_{1640})}$
30	Normalized Difference Water Index (NDWI)	$NDWI = \frac{(\rho_{1240} - \rho_{1640})}{(\rho_{1240} + \rho_{1640})}$
31	Normalized Multi-band Drought Index (NMDDI)	$NMDDI = \frac{\rho_{680} - (\rho_{680} - \rho_{1130})}{\rho_{680} + (\rho_{680} - \rho_{1130})}$
32	Water Band Index (WBI)	$WBI = \frac{\rho_{910}}{\rho_{900}}$



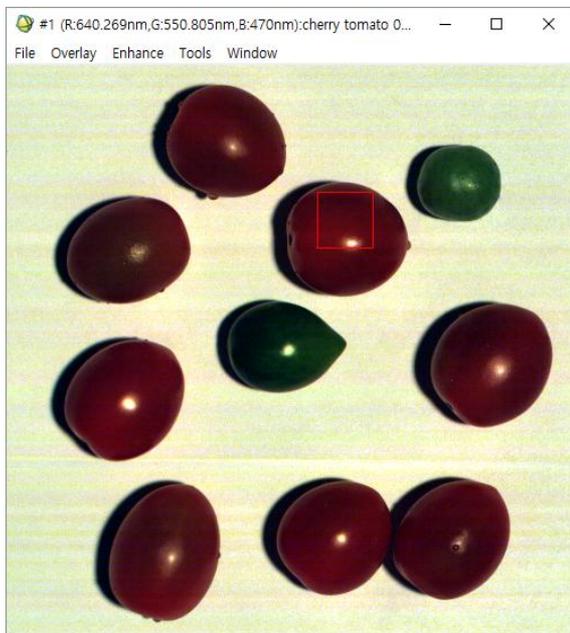
식물의 상태에 따른 파장별 반사율

농업 - 식생 지수(Vegetation Index)

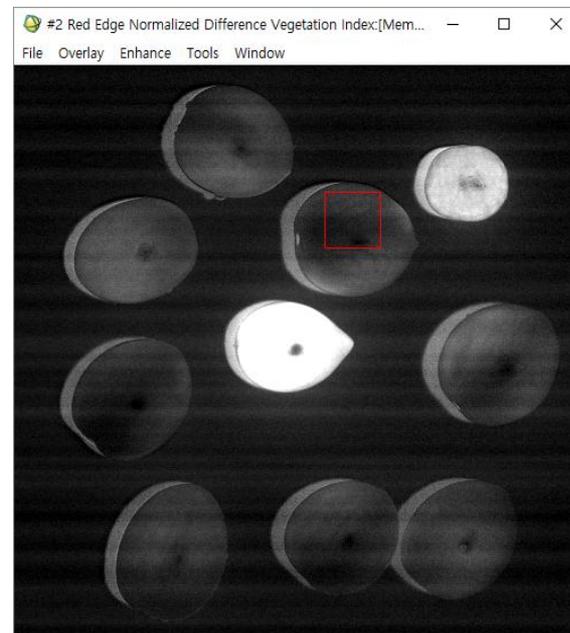


농업 - 정규 식생 지수(NDVI)

True color image



Red Edge NDVI

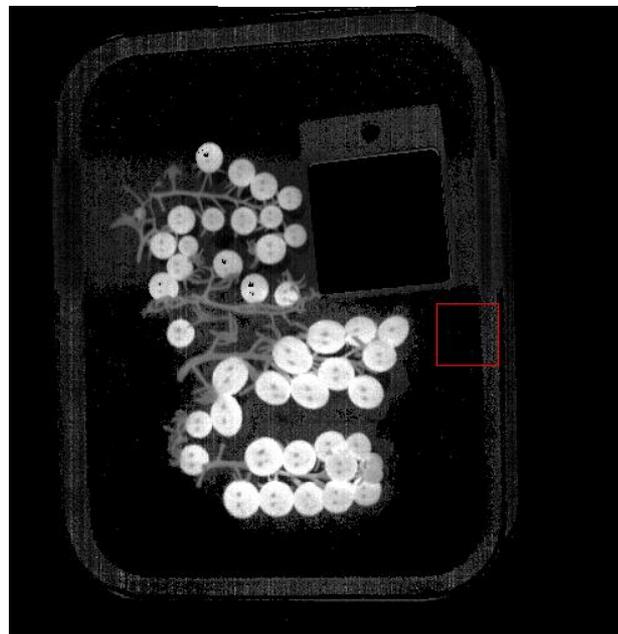


농업 - 수분 함량 지수 (WBI)

식생 캐노피 수분 함량 변화에 따른 특성



$$WBI = \frac{\rho_{970}}{\rho_{900}}$$

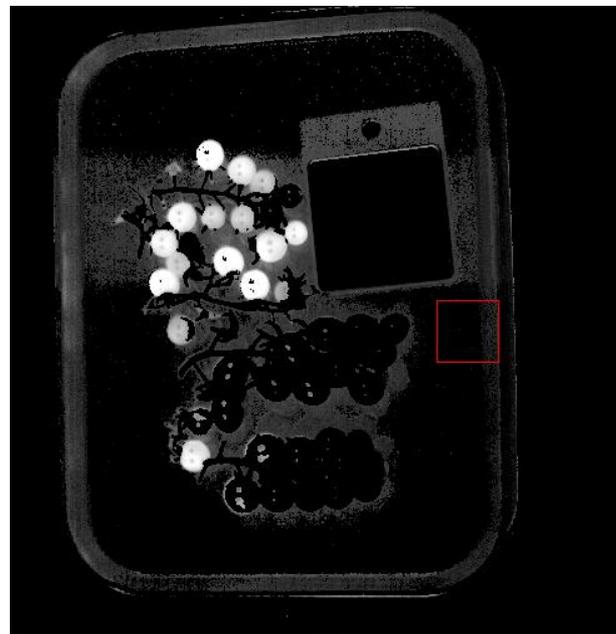


농업 - 식생 지수 : 식물 노화 지수 (PSRI)

Carotenoid와 Chlorophyll의 비율을 통한
식생의 스트레스 혹은 숙성도



$$PSRI = \frac{\rho_{680} - \rho_{500}}{\rho_{750}}$$

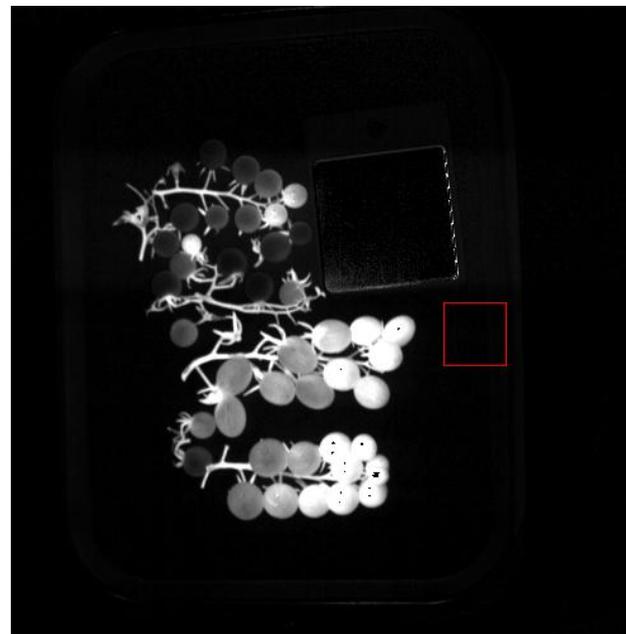


농업 - 식생 지수 : 식생 강조 지수 (EVI)

토양 및 대기의 영향을 줄인 식생의 감도



$$EVI = 2.5 * \frac{(NIR - Red)}{(NIR + 6 * Red - 7.5 * Blue + 1)}$$

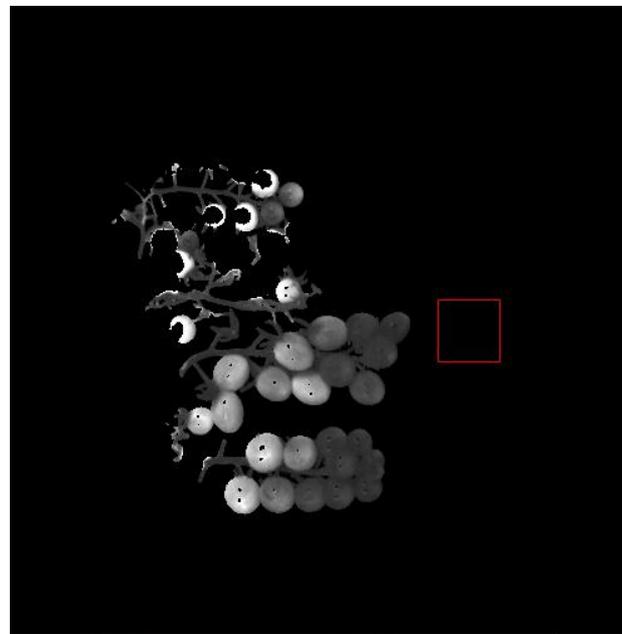


농업 - 식생 지수 : 색소 둔감 지수 (SIPI)

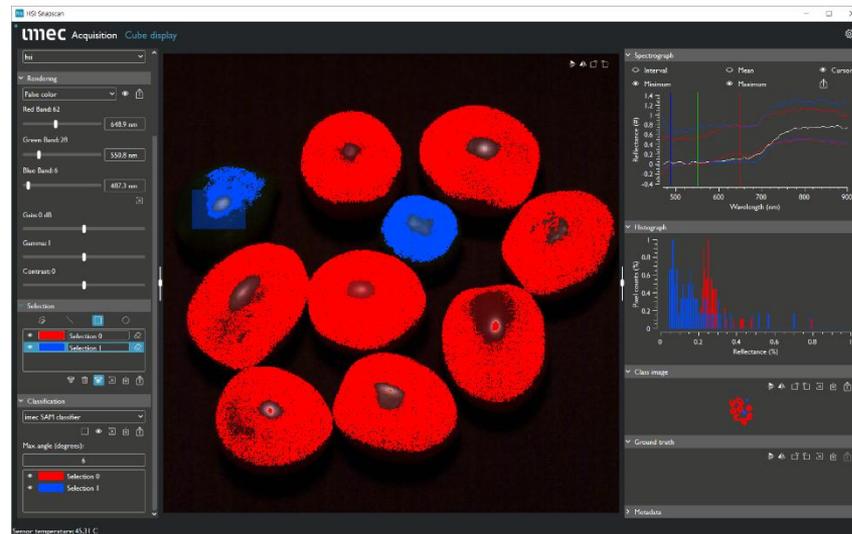
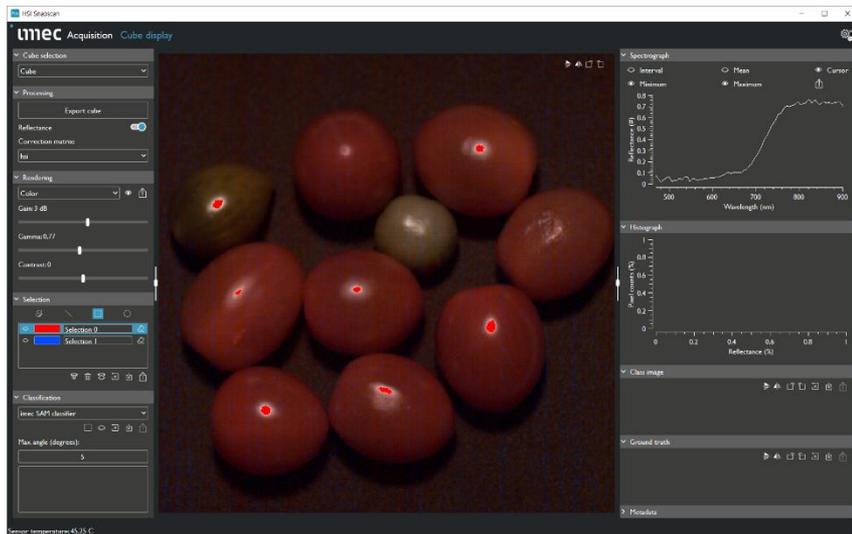
식생의 Carotenoid 와 Chlorophyll 의 비에 대한
민감성을 이용한 식생지수



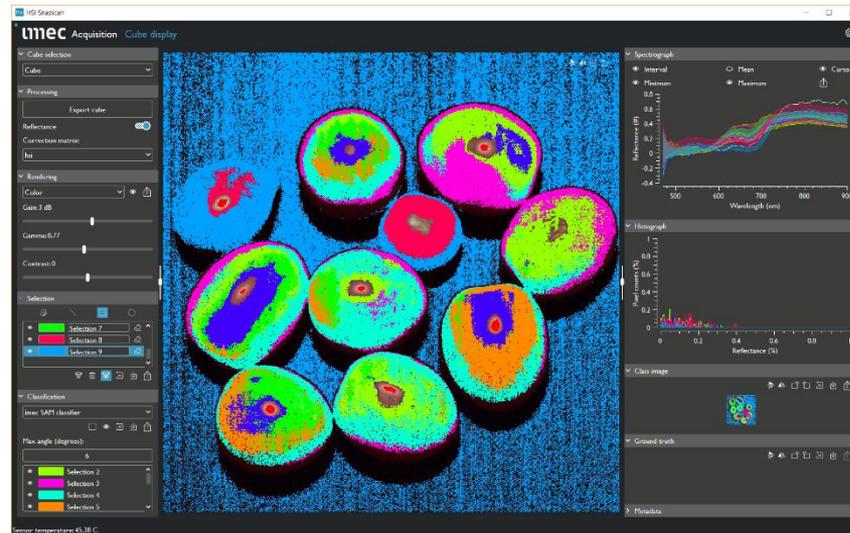
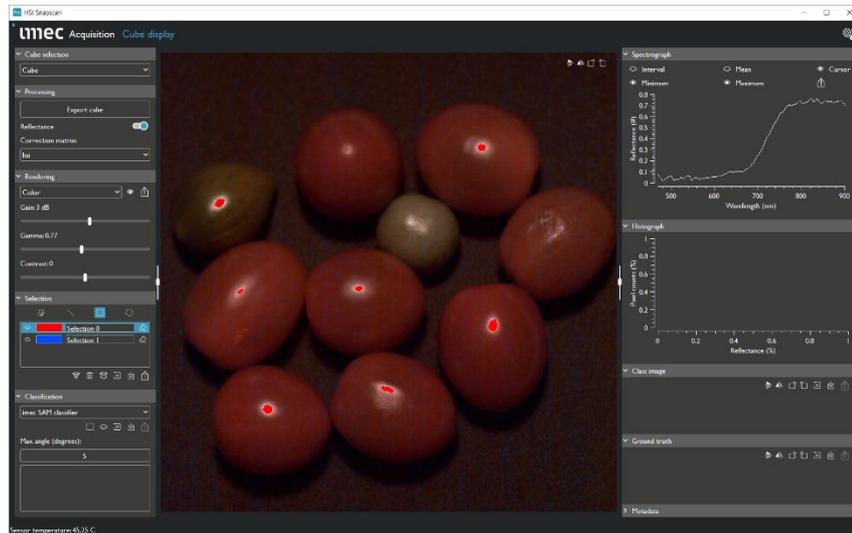
$$SIPI = \frac{\rho_{800} - \rho_{445}}{\rho_{800} - \rho_{680}}$$



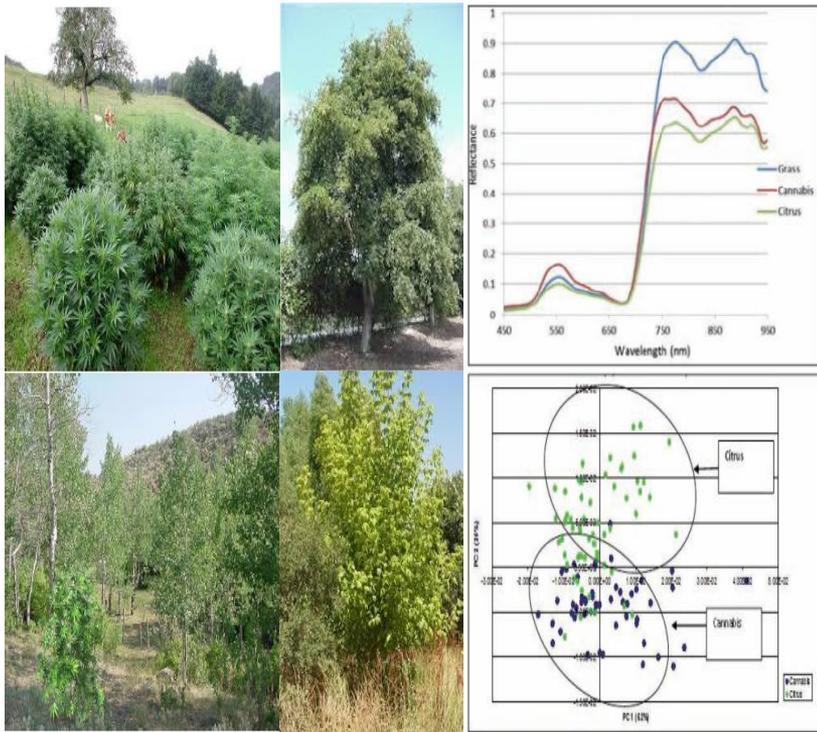
농업 – SAM Classification



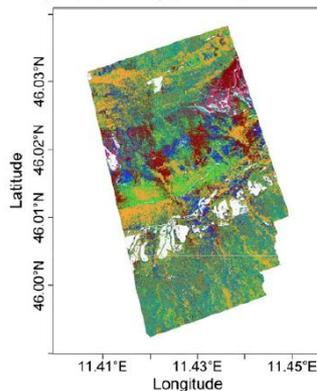
농업 – SAM Classification



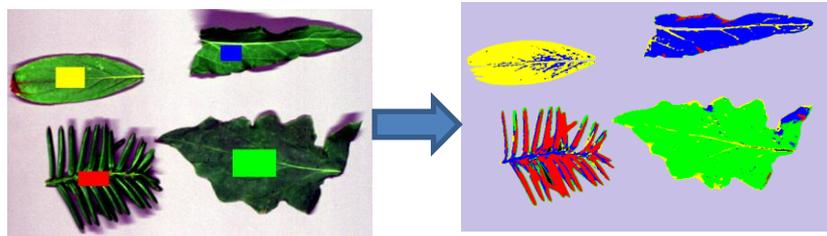
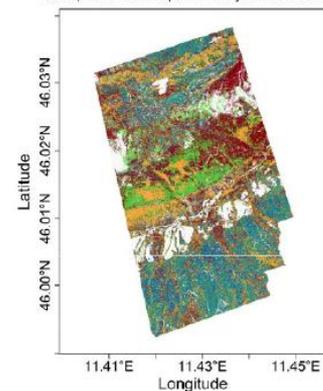
산림 - 수종 분류



Hyperspectral and high point density LIDAR features

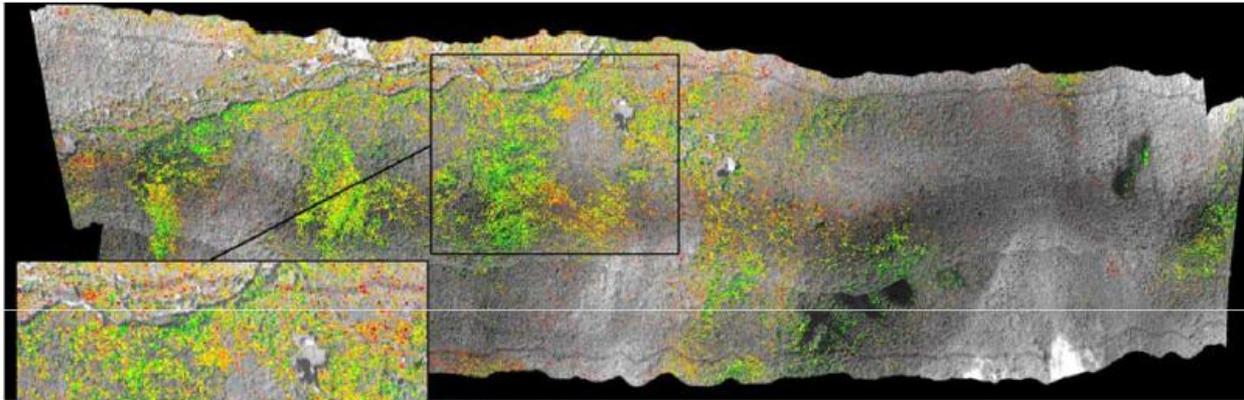


Multispectral and low point density LIDAR maximum

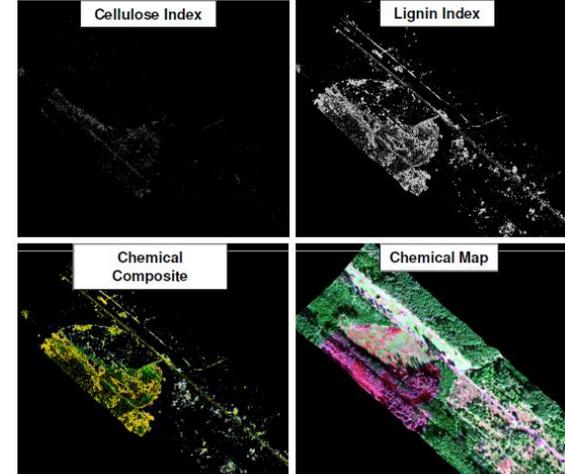
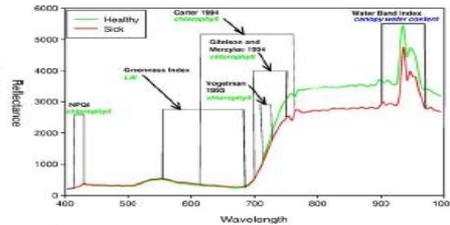


분광 정보를 이용한 정밀한 수종 분류

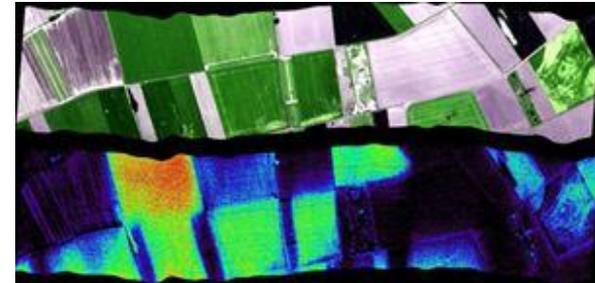
산림 - 모니터링



- Healthy trees
- Slight decline in health
- Moderate decline in health
- Unhealthy trees



Data collection and preprocessing: Specim 2013, Analysis Images: Exogenesis

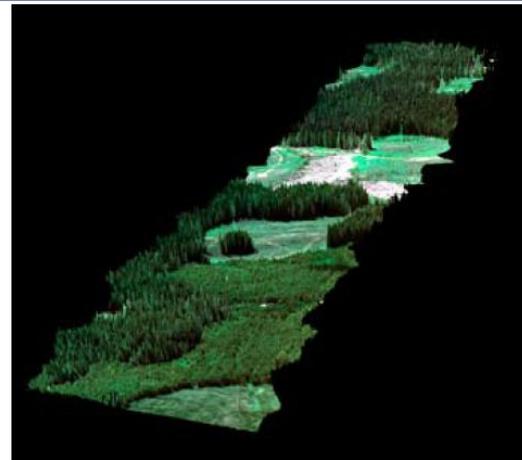


산림의 활력도/건강도 모니터링

산림 - 수목 총량 산출

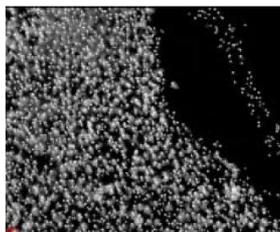


Sidney Island

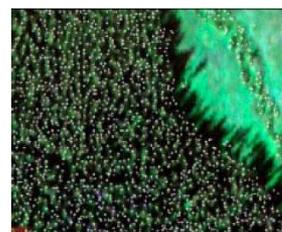


Single flight line

LIDAR 고도 모델에 초분광 data를 입힌 모습



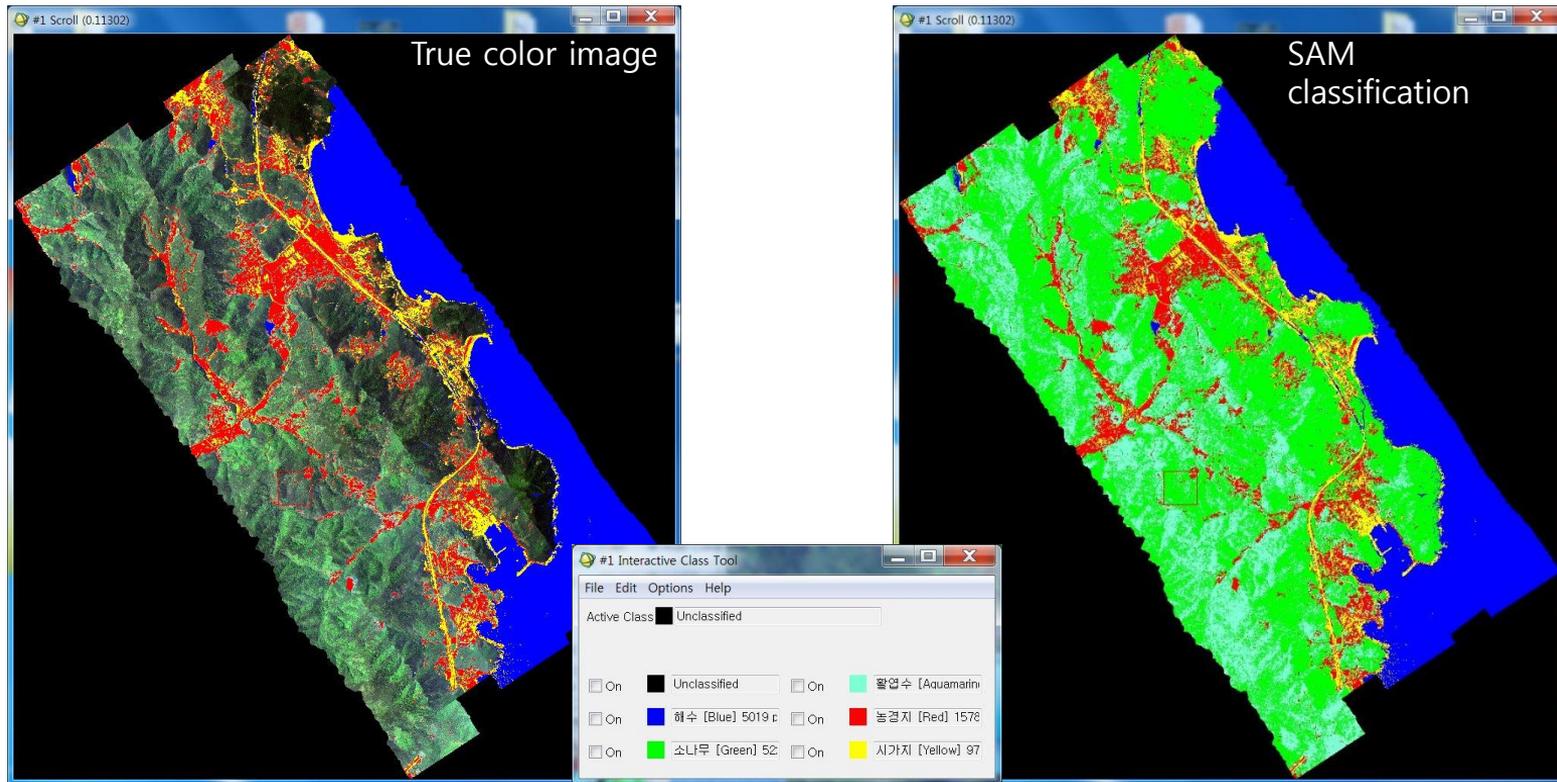
LIDAR canopy height model



결합 데이터 샘플

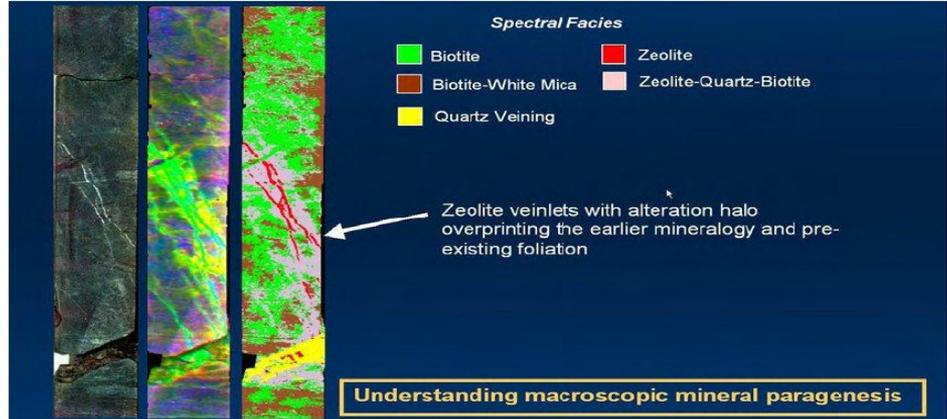
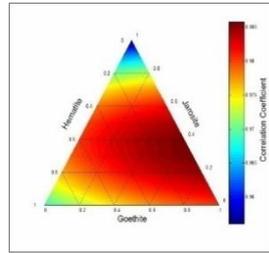
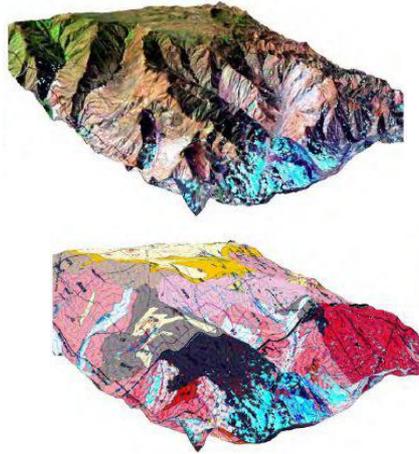
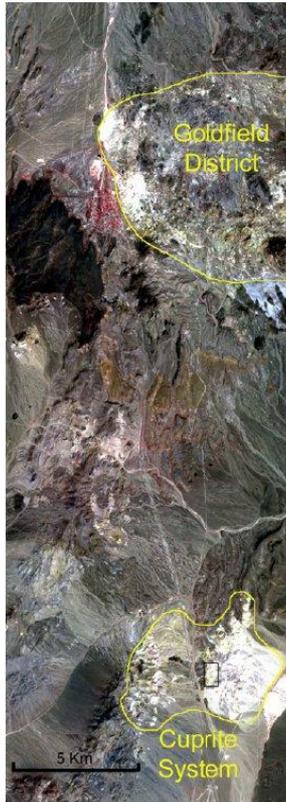
LIDAR의 지형 정보와 초분광 영상 정보를 결합하여 수목의 총량 산출

산림 - 재선충병 조기 탐지



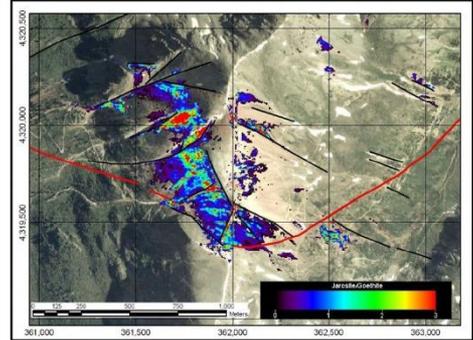
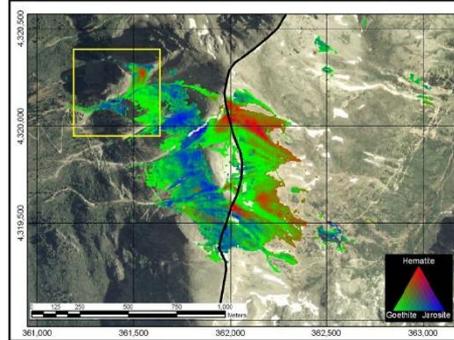
소나무 재선충병 조기 탐지를 위한 초분광 항공촬영 - 국립산림과학원(거제도 대금산 일대)

지질 - 광물 탐사

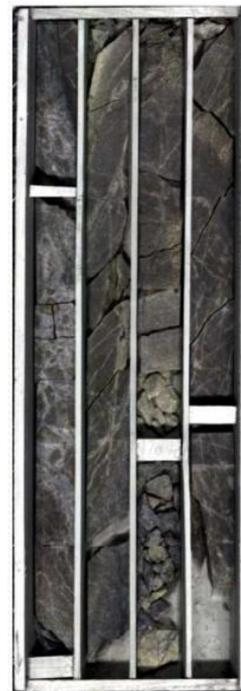


Greywacke with zeolite-quartz veining

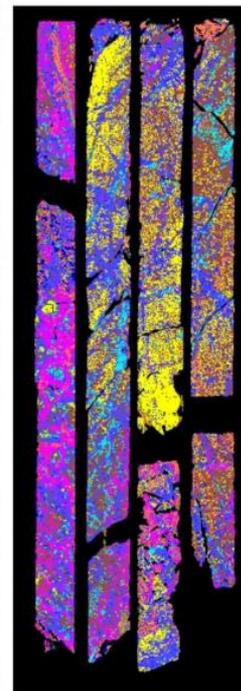
40mm



지질 - Core 분석



False Colour Composite Image



Mineral Classification Image

FerroMagnesian Minerals

- Amphibole
- Biotite
- Chlorite
- Epidote

Clay Minerals

- Mg-Smectite
- Nontronite
- Kaolinite
- Al-Smectite

White Mica Minerals

- Hydrous Micas (Smectite-Illite)
- Intermediate Micas (Illite)
- Anhydrous Micas (Sericite)

Other Minerals

- Non-phylosilicates (Quartz-Feldspar)

SisuROCK Hyperspectral Core Imaging Station을 활용한 drill core scanning

지질 - 퇴적물 분류

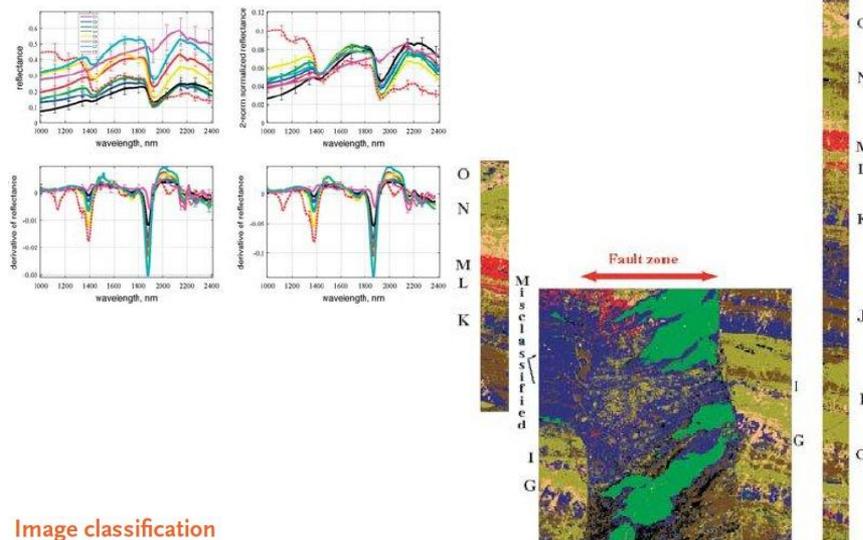
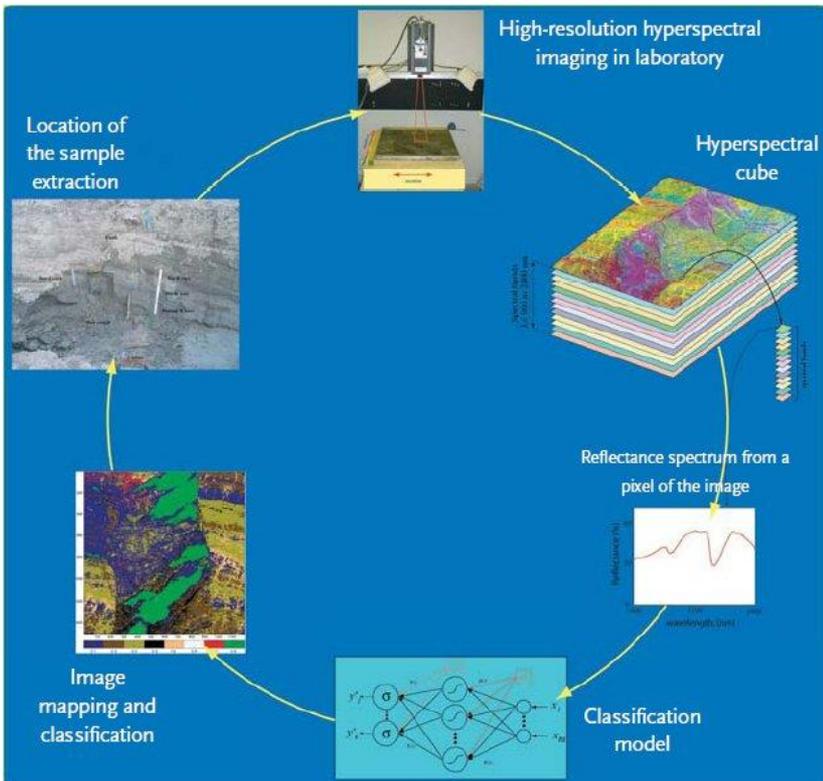
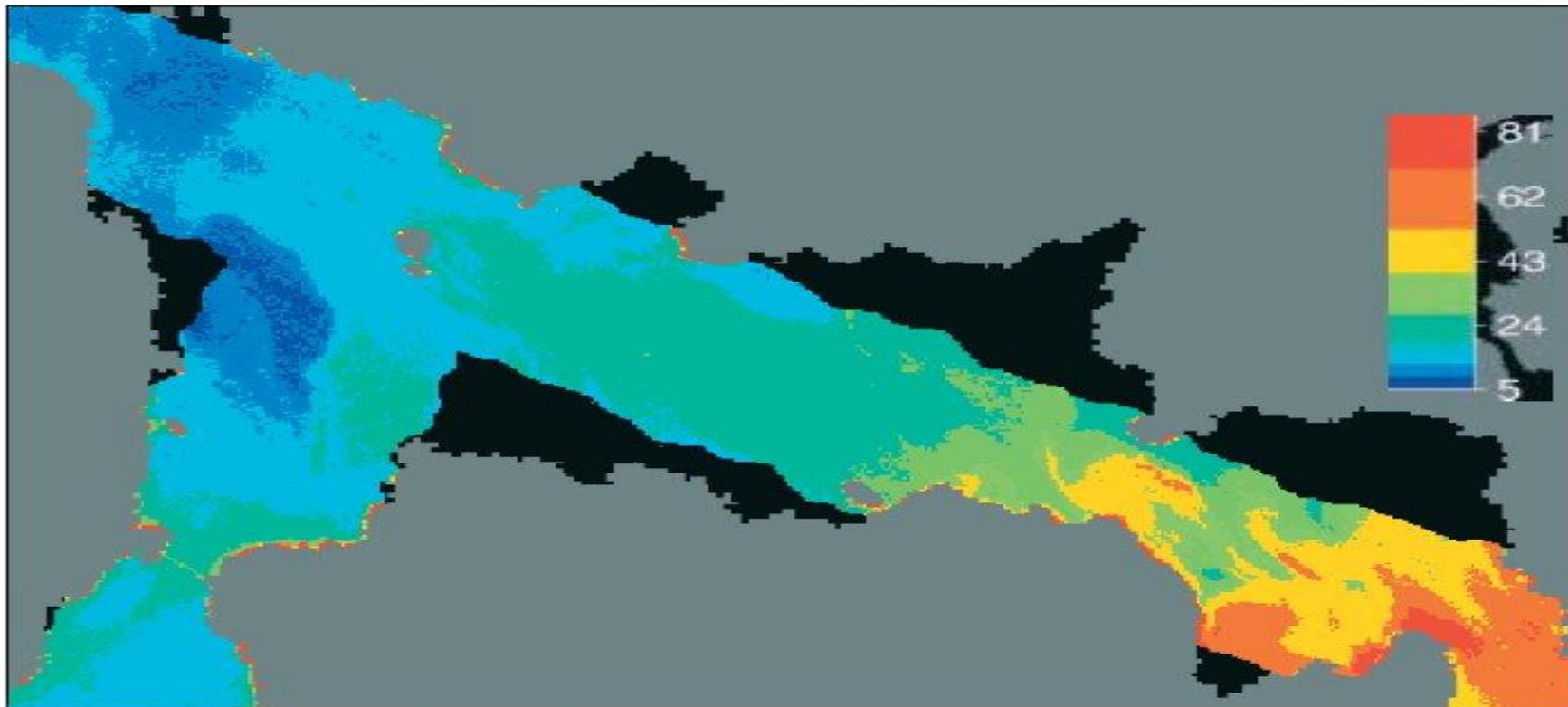


Image classification

CLASS NUMBER	NUMBER OF EXAMPLES	MATERIAL TYPE
Class 1	1430	Sandy-slit
Class 2	2530	Clayey-slit
Class 3	1750	Clayey-slit w/CO ₃
Class 4	85	Organic material
Class 5	332	Carbonate mix
Class 6	95	Wood toothpick
Class 7	316	Sandy-slit w/CO ₃

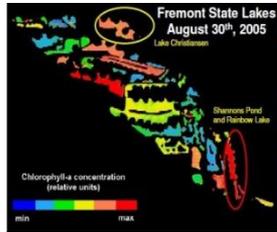
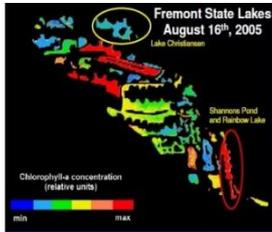
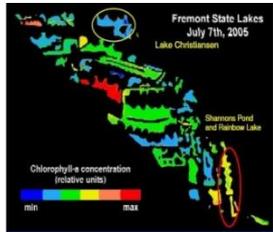
퇴적물 층위와 구조에 대한 분석, 데이터 수치화 및 분류

수질/수자원 - 면단위 수질 감시

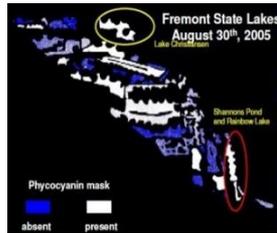
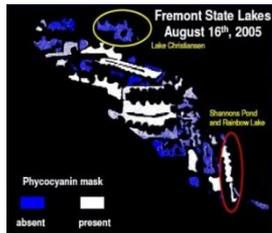
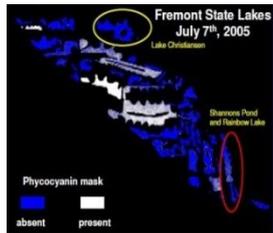


하천의 식물성 플랑크톤 농도 분포

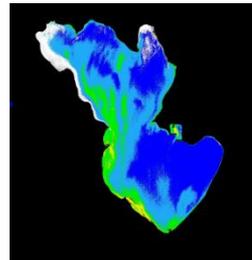
수질/수자원 - 모니터링



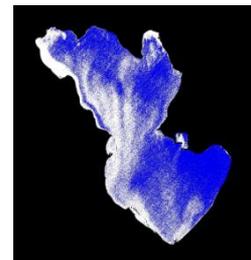
엽록소 농도 변화량



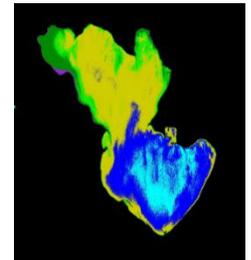
피코시아닌 농도 변화량



Chlorophyll-a map



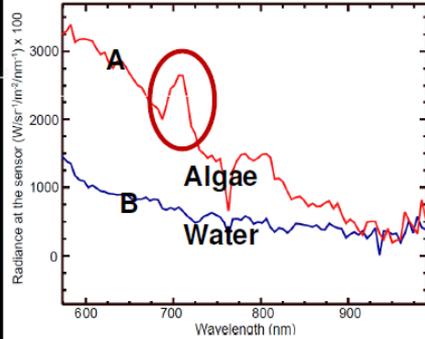
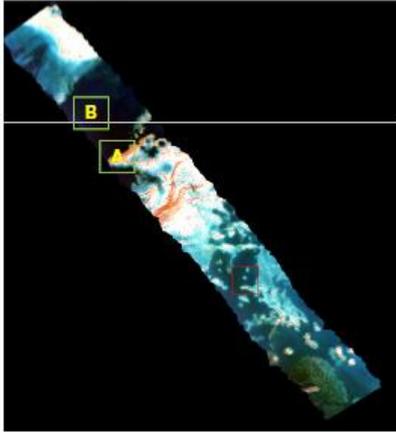
Phycocyanin map



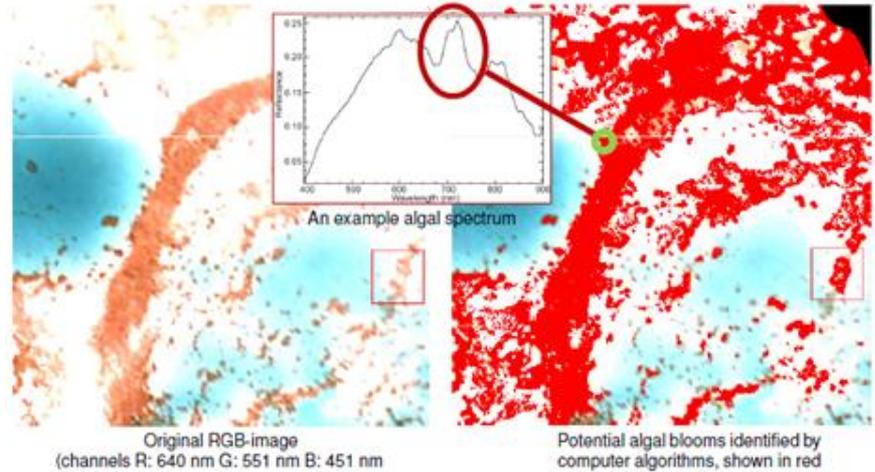
Total solids content

Chlorophyll-a, Phycocyanin 농도의 시공간적 변화량 모니터링

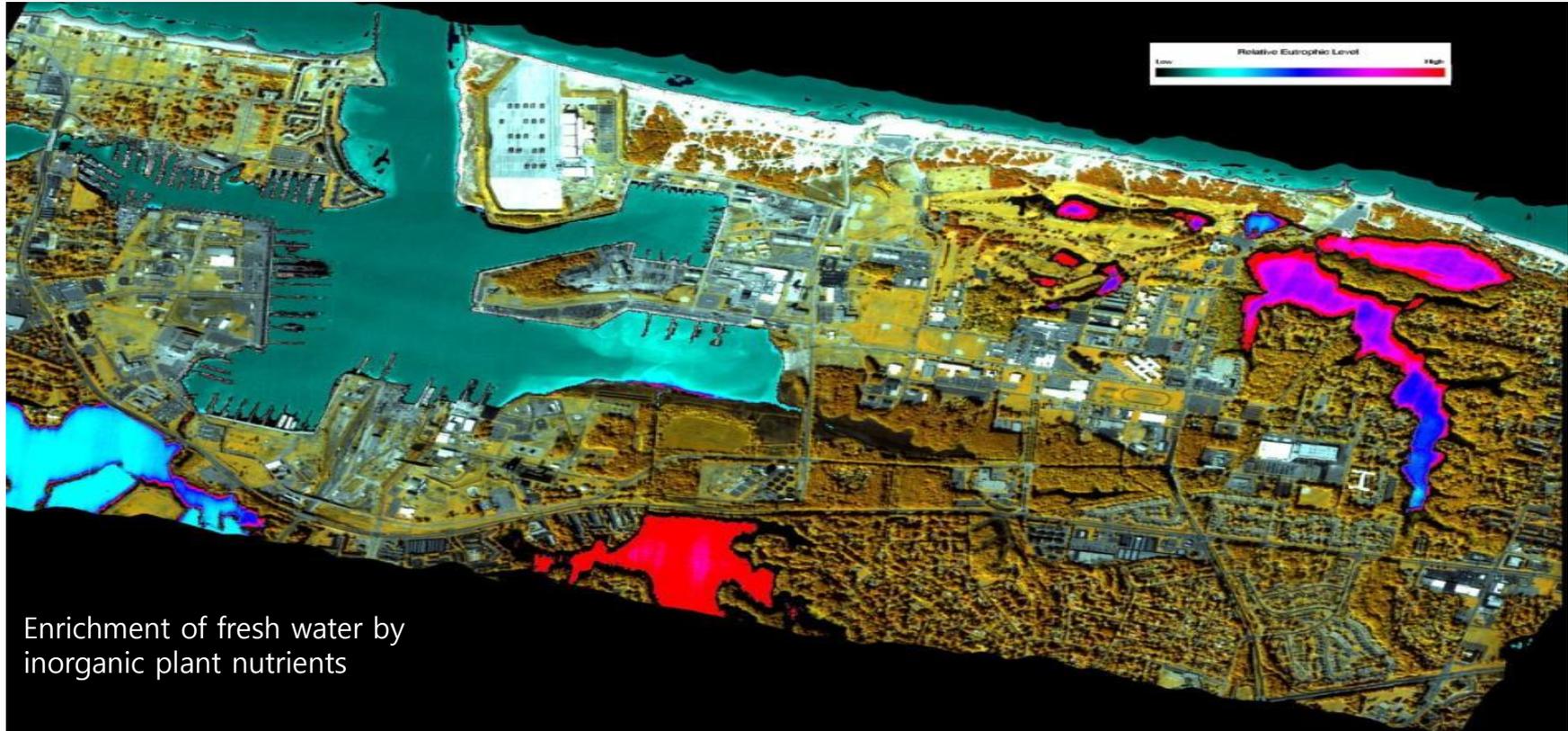
수질/수자원 – 유해 조류 모니터링



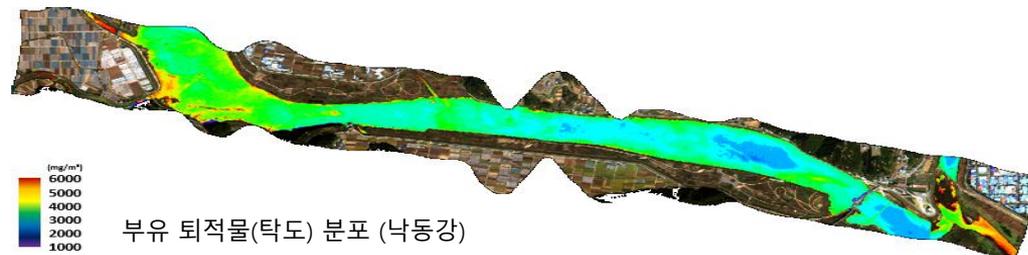
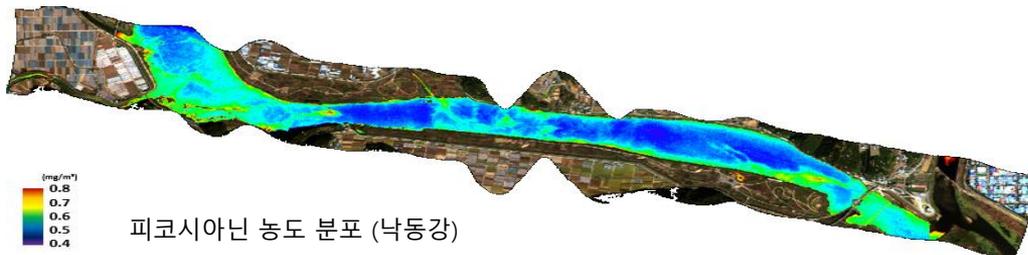
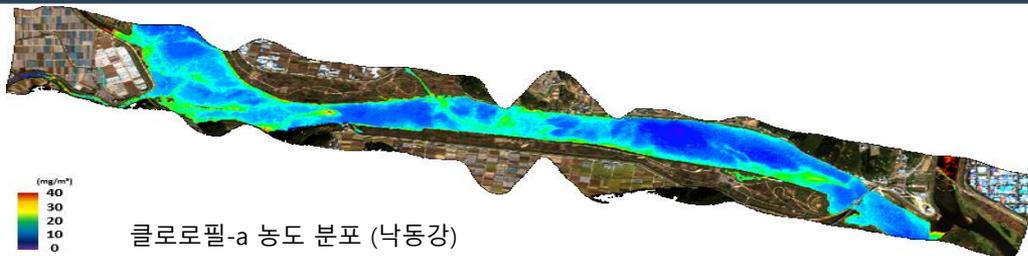
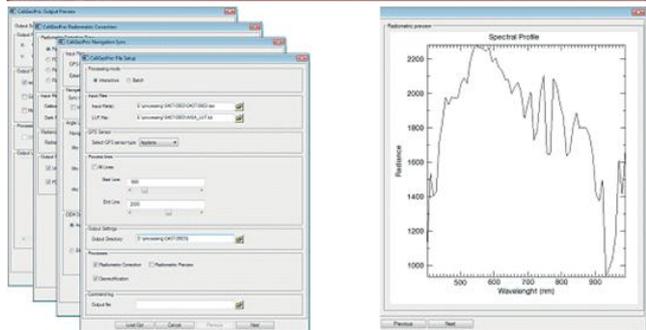
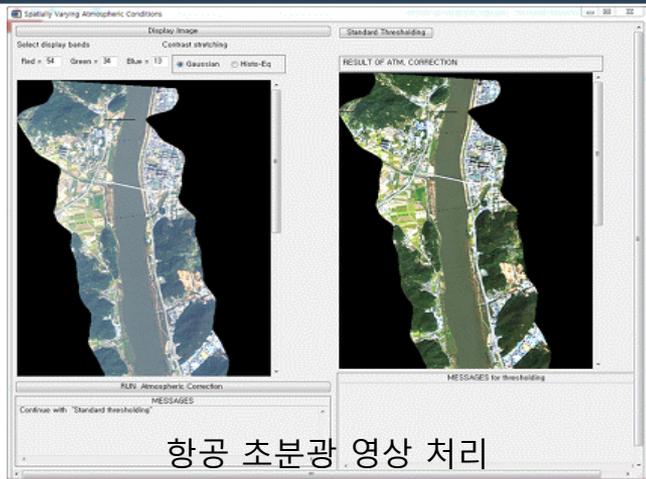
Detection of harmful algal blooms by airborne hyperspectral remote sensing



수질/수자원 - 부영양화 모니터링



수질/수자원 - 4대강 녹조 모니터링

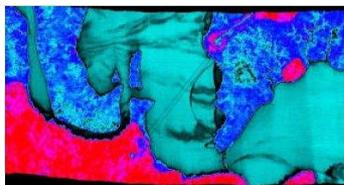


하천 수계 녹조 정량 분석 - 국립환경과학원(4대강 녹조 모니터링 사업)

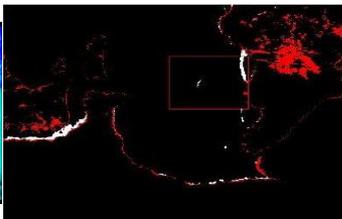
환경 - 원유 유출



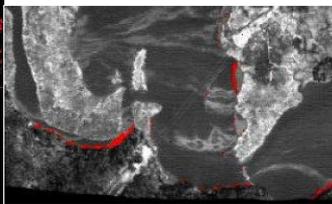
유출 직후 촬영 사진



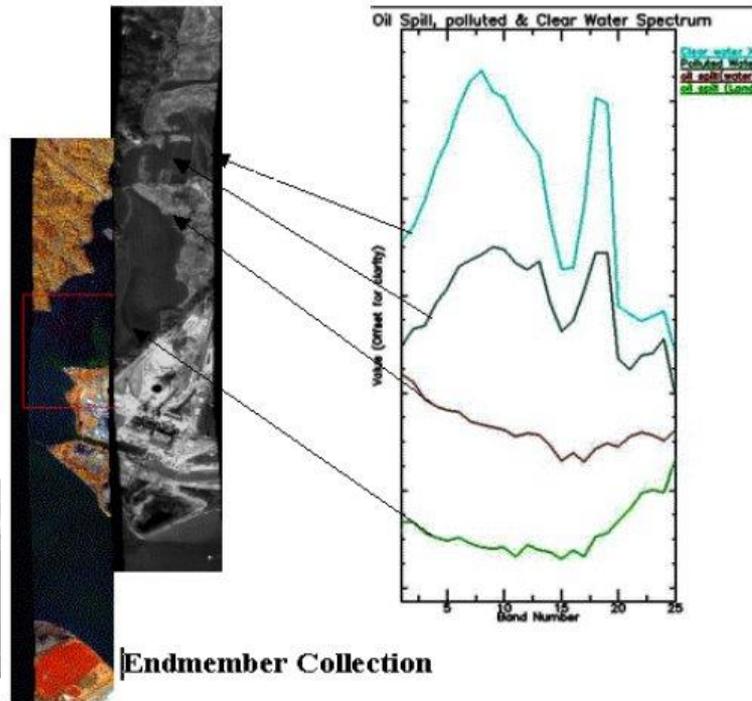
Black : 오염된 물



Red : 지면 유출 원유
White : 강물 유출 원유

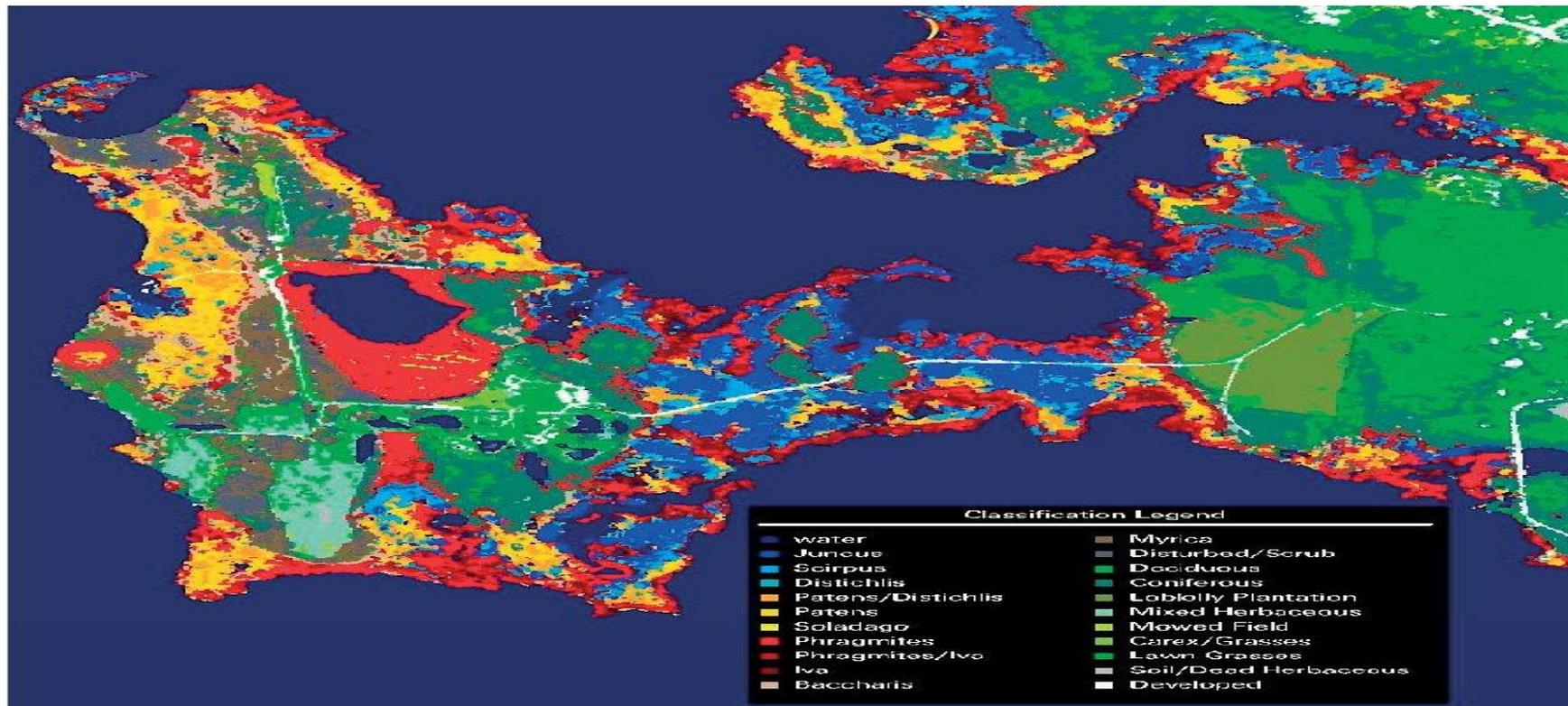


Red : 강물 유출 원유



분광 그래프의 명확한 특성 차이로 오염 유무 검출

환경 - 습지 연구



분광 이미지를 이용한 습지의 식생 분포도

환경 - 홍수 재해 예방



The town of Szeged, Hungary

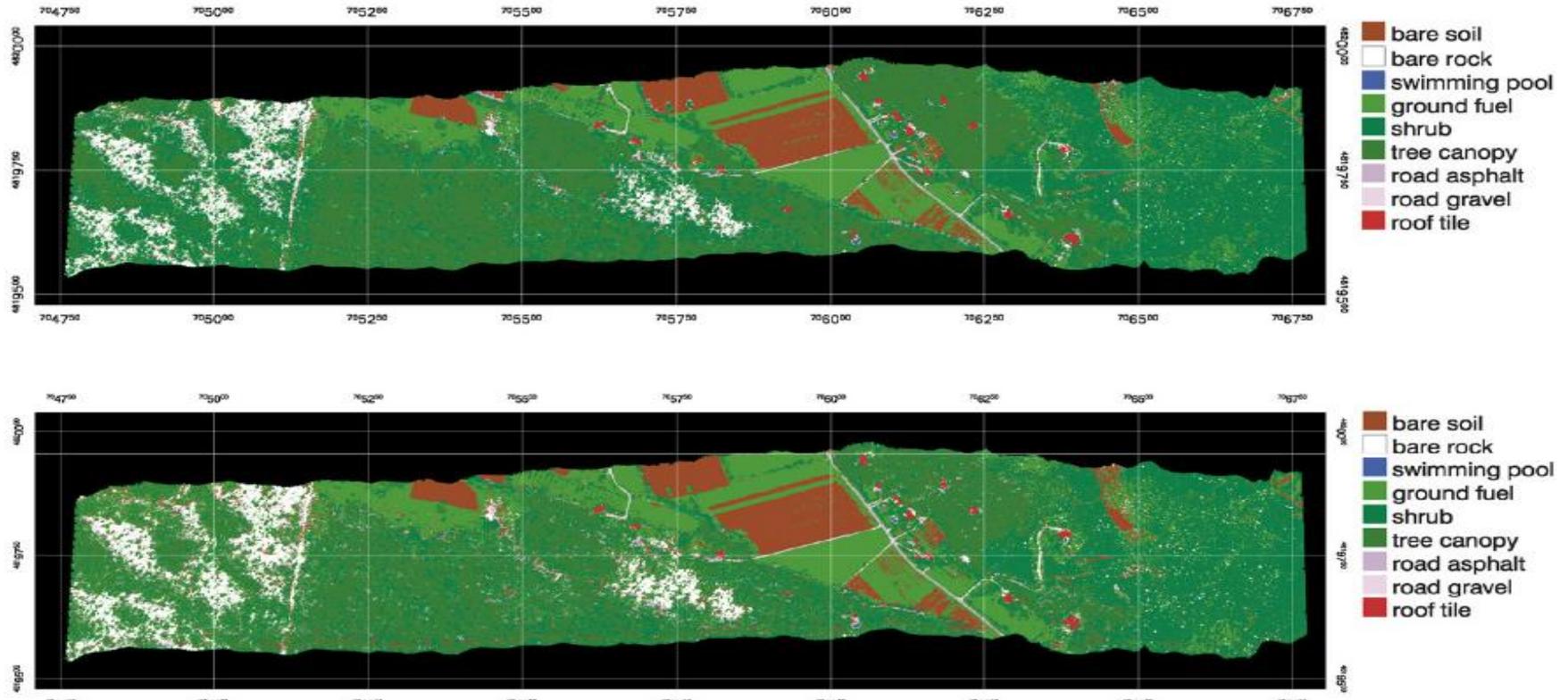


- Unclassified
- Vegetation
- Bare
- Building
- Roads
- Grass
- Water



NIR 또는 MWIR 파장대역의 표준화된 식생 지표를 통해 지형에 대한 함수량을 계산하고 홍수 위험도를 판단

환경 - 산불 위험 지역 감시



Koetz, B., Morsdorf, F., van der Linden, S., Curt, T. And Allgöwer, B. (2008) : Multi-source land cover classification for forest fire management based on imaging spectrometry and LiDAR data. Forest Ecology and Management 256, 263-271.

국방 - 위장물 탐지



SAAB Barracuda Camouflage Net over Ammo Dump



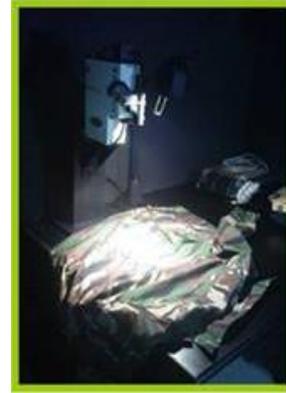
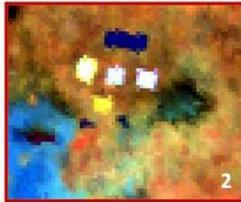
Camouflaged targets visually "disappear" into background. Visible region insufficient to positively discern camouflaged target(s)

Hyperspectral Enhancement

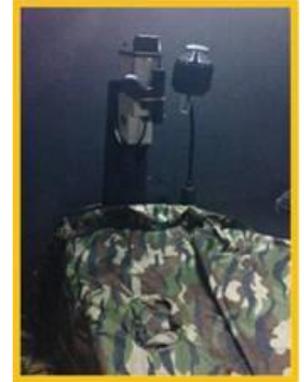


- Processed high resolution hyperspectral image:
- Background information suppressed
 - Spectral anomaly isolated and amplified
 - Camouflage target isolated from background
 - Positive target ID

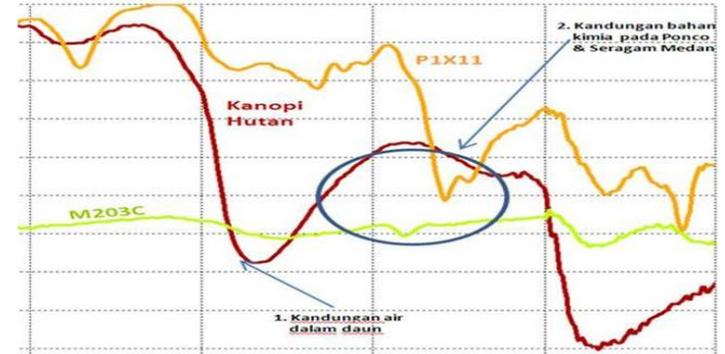
국방 - 위장물 탐지



Material M203C



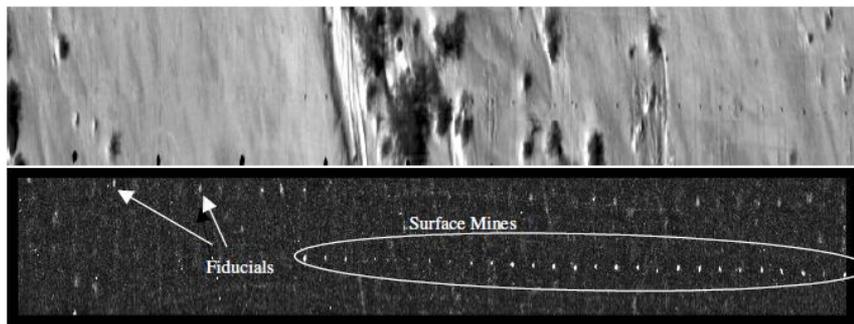
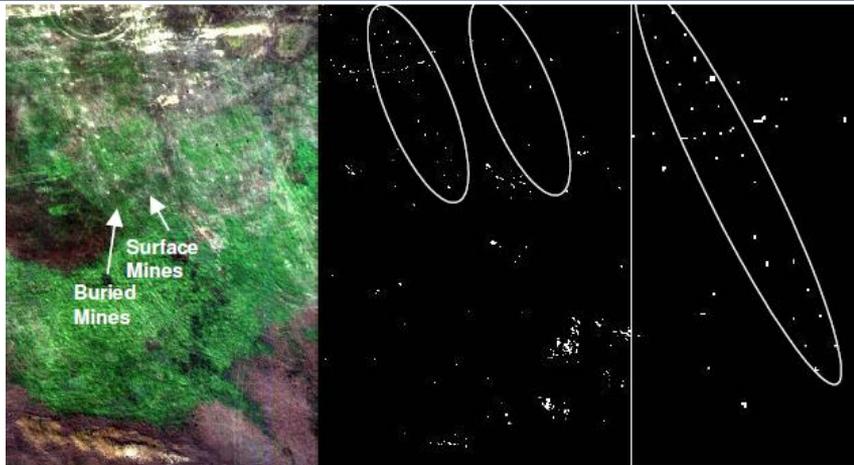
Material P1X11



AISA Eaglet (Helicopter@1600ft, 0.4m GSD)

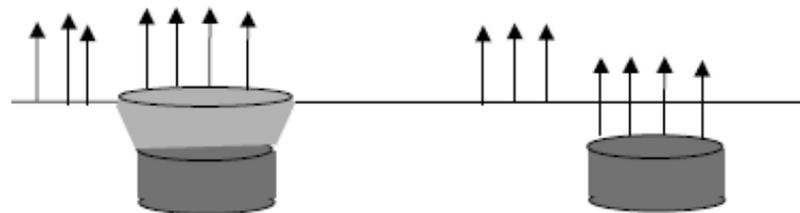
Sarawak in Malaysia

국방 - 지뢰 탐지



Spectral Detection

Temperature Detection



분광 데이터, 온도 정보 및 지뢰의 군집 특성을 이용한 탐지

국방 - 초분광 영상 감지기

빈 라덴 제거 작전에 동원된
미 첨단 무기·장비



RQ-170 센티널 무인정찰기

빈 라덴 제거 작전 상황 영상을 실시간으로 백악관에 전달



스텔스 UH-60 블랙호크(기존 블랙호크를 스텔스로 개조)

파키스탄 레이더망 피해 네이비실 대원 태우고
빈 라덴 저택 기습 (사진은 블랙호크)

레이저 도청장치
빈 라덴 저택 유리에 레이저 발사해
내부 거주자들의 대화 도청



빈 라덴 은신처



초분광 영상감지기

네이비실 대원들이
착용하고 작전하며
급박한 상황에서
적군과 아군 구별

M4A1 5.56mm
자동소총

9mm 권총

칼

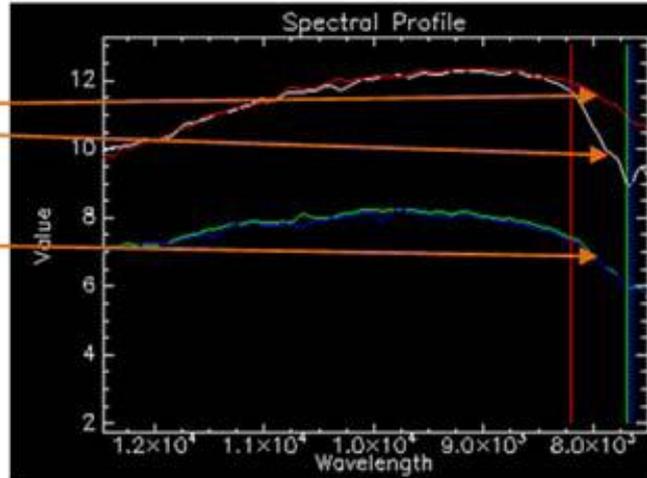
방수군화

안전전자감식장치

지문과 안면 홍채
정보를 인식해
사살된 사람이
빈 라덴인지를 확인



국방 - 가스 탐지



- LWIR 파장 영역에서 온도 차이에 의해 나타나는 분광 특성을 활용한 가스 검출
- 사용 Sensor : Aisa OWL
 - 측정 파장 범위 : 7600 -12400nm
 - 대상 Gas : Methane, Ammonia, Ozone, Tetra-fluoroethane propellant

문화재 - 미술품 감정



RGB image



SWIR at 1600nm



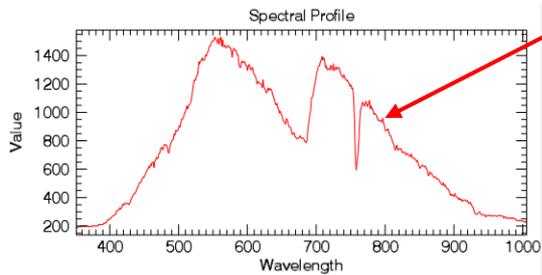
X-ray

육안 확인이 안되는 밑그림, 덧칠 및 안료 분석을 통한 연대 추정 - Composition by Henryk Statewski, 1957, oil

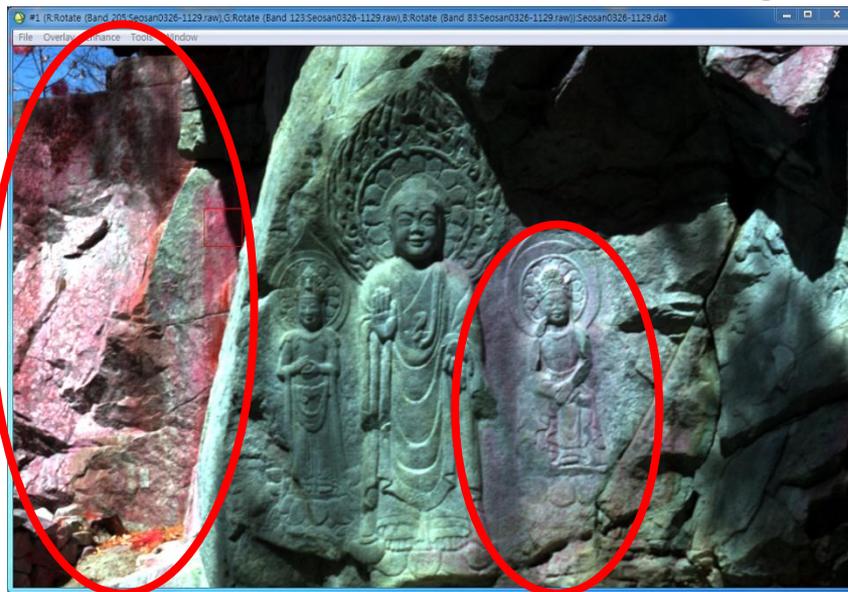
문화재 – 석조 문화재 모니터링



충남 서산 마애삼존불상

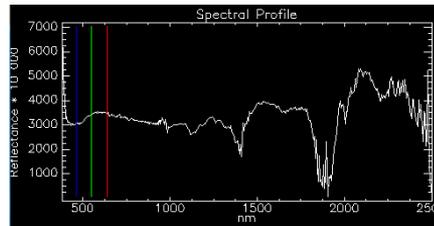
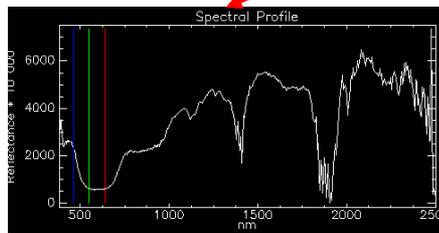
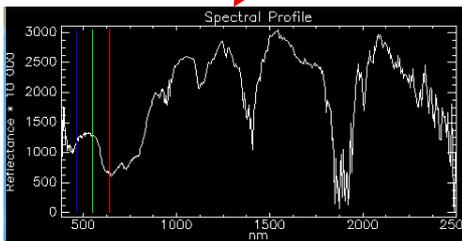
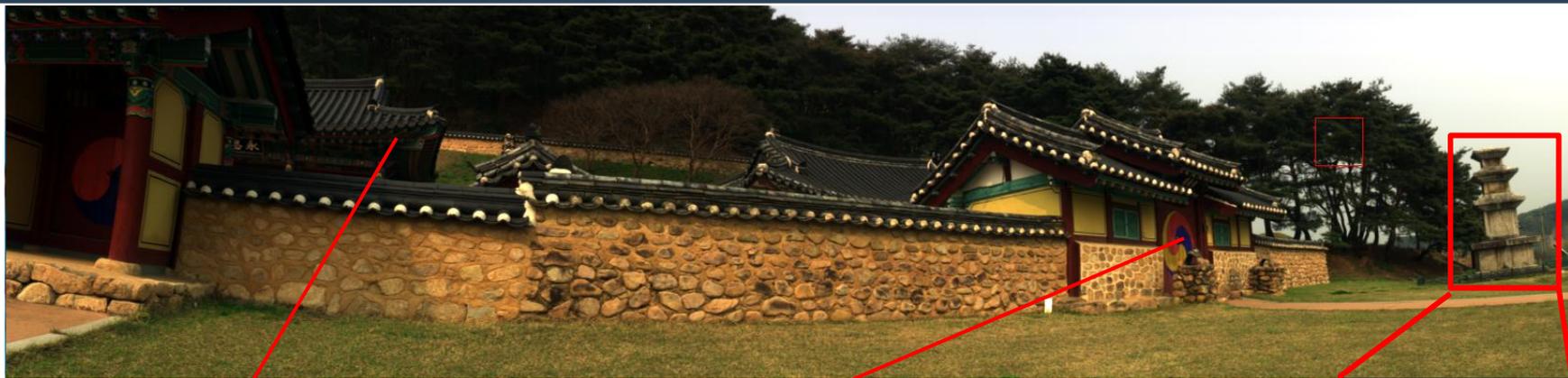


이끼 부분을 붉은색으로 표현하고 있는 CIR image



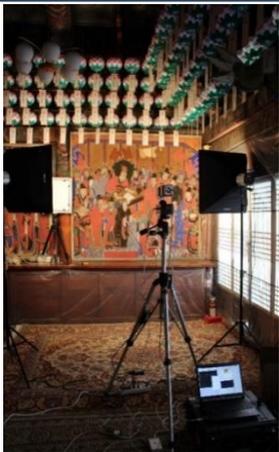
석조 문화재 풍화작용의 원인이 되는 이끼 및 수분의 검출 - 국립문화재연구소

문화재 – 풍화 상태 및 노후화 분석



석조 문화재/단청 등의 풍화 상태 및 노후 정도 파악 – 국립문화재연구소(경북 상주 화달리 삼층석탑)

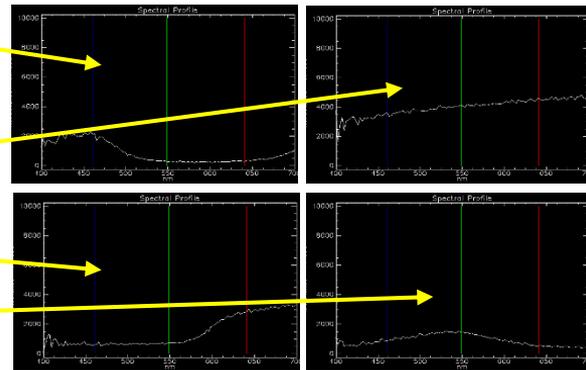
문화재 – 안료 측정



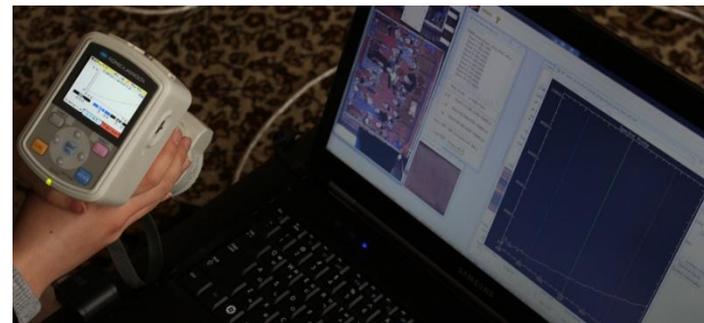
초분광 카메라 촬영



분광측색계 측정



- 접촉식 측정장비와 Profile 비교
- 문화재에 훼손을 줄 수 있는 접촉식 장비 대체



안료 특성 분석 및 훼손 대비를 위한 노후 정도 파악 – 한국전통문화대학교(보광사 대웅보전 내 불화)

토양 - 중금속 농도 분포

- Co, Fe, Pb, Cr, Ti, Cu, Zn, Mo, Sr, V, Zr, Ba, Mn, As 등 14개의 중금속 물질에 대한 원격 계측
- 위성 영상, 시료 채취, 지상 분광기 활용
 - 지상 초분광 데이터와 상관성 분석을 통해 농도 분포도 작성
- 공통된 연구대상 물질 : Pb, Cu, As
 - 결정 계수(coefficient of determination, R2)
 - Pb : 0.61 , Cu : 0.27 , As : 0.50

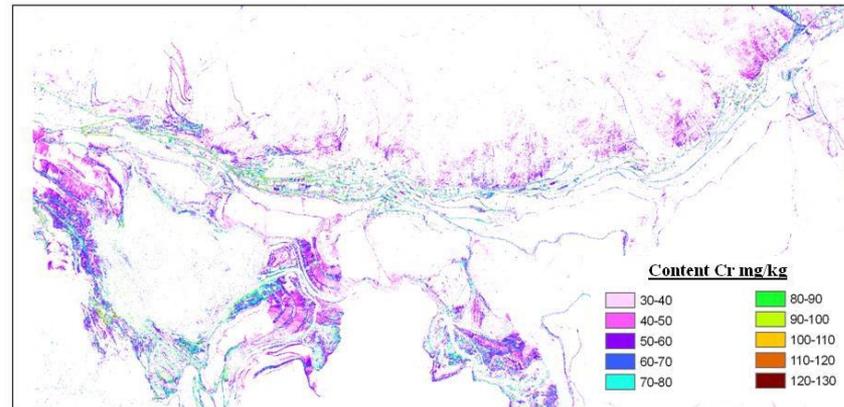
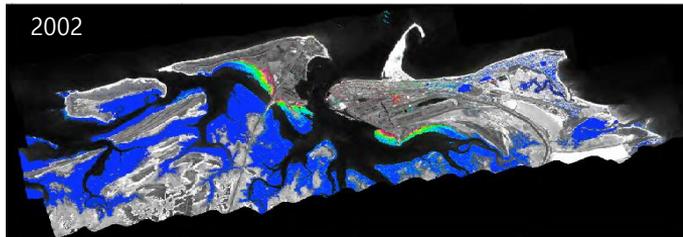
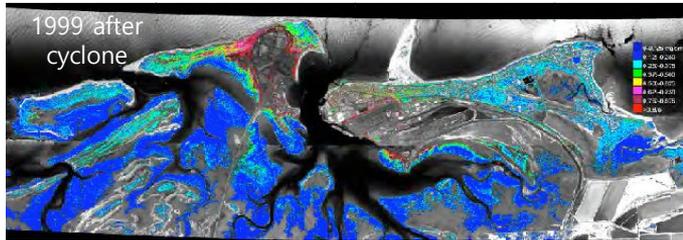
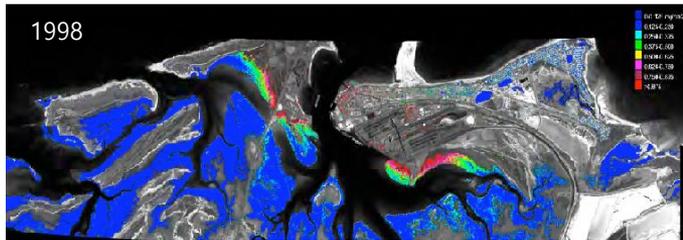


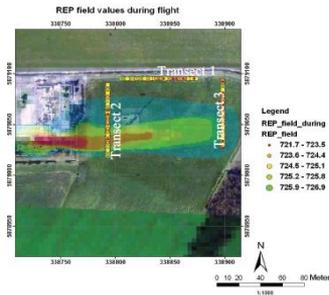
표 8. 위성 분광자료와 실측 자료의 연구대상 물질별 상관계수 (Asmeryan Ch. G. et al., 2013)

	2005		2012	
	Spectral wavelength (nm)	Correlation coefficient (R ²)	Spectral wavelength (nm)	Correlation coefficient (R ²)
Co	401	0.22	1033	0.12
Fe	2476	0.29	2206	0.14
Pb	2498	0.61	1282	0.21
Cr	2500	0.28	2460	0.34
Ti	2498	0.51	1639	0.27
Cu	1251	0.27	402	0.31
Mo	685	0.33	408	0.24
Zn	2498	0.56	1720	0.33
Sr	1199	0.30	408	0.34
V	2498	0.38	408	0.16
Zr	2498	0.21	408	0.25
Ba	417	0.44	713	0.10
Mn	2114	0.50	1654	0.37
As	-	-	770-895	0.50

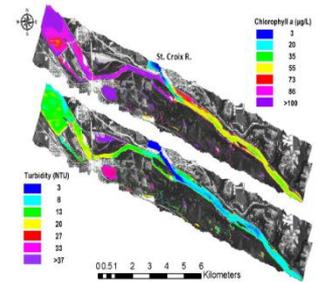
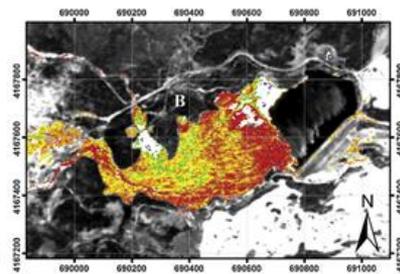
토양 - pH 모니터링



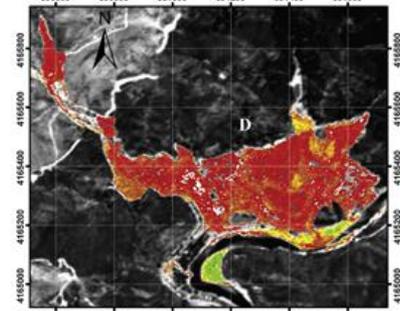
토양 내 산화철 모니터링(CSIRO, 2005)



토양 내 유류유출 (BROWN, 2009)



하천 내 Chl-a (Olmanson et al., 2013)



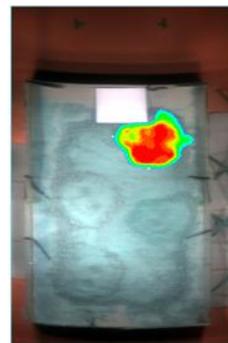
pH ranges ■ 1.0-1.9 ■ 2.0-2.9 ■ 3.0-3.9 ■ 4.0-4.9 ■ 5.0-5.9 ■ 6.0-6.9 ■ 7.0-7.9

토양 pH 모니터링(N. Zabcic et al., 2014)

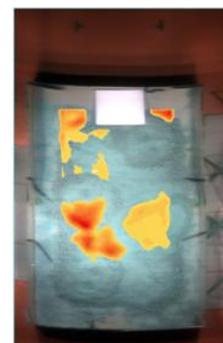
토양 - 중금속 오염 모니터링



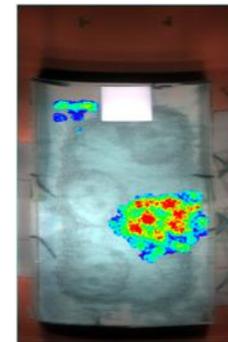
Lab-scale 장치 구축, 분광 라이브러리 적용 영상 최적화



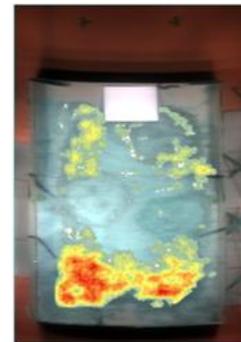
As



Cd



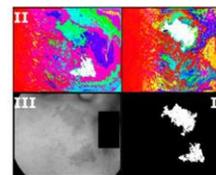
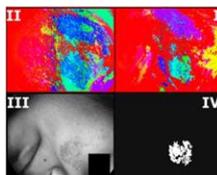
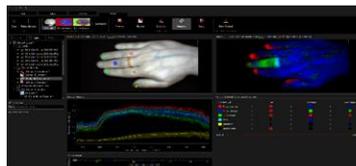
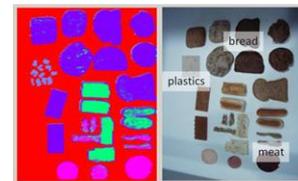
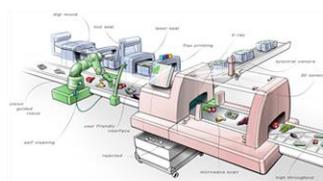
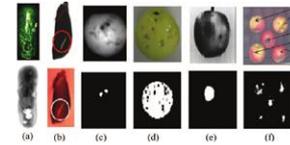
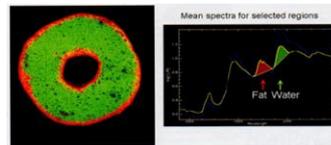
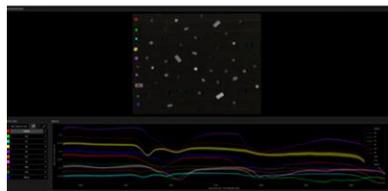
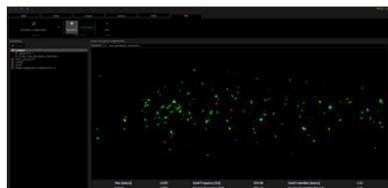
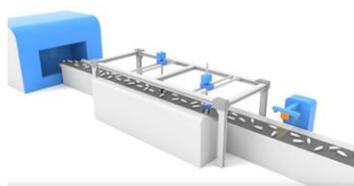
Cu



Pb

토양 내 4대 중금속(As, Cd, Cu, Pb) 탐지 및 농도 분석 - 환경부 연구과제

기타



머신비전 – 결함, 이물 등의 검사

식품, 재활용, 의료, 화장품 등

THANK YOU
