Low Cost Hyperspectral Imaging for Drones

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OUTLINE

1. Introduction - where to do I come from?
2. Basic Spectroscopy – a repetition!
3. Hyperspectral – what is it?
4. Sample data from Svalbard – what has been done?
5. Instrumental development – how to we make one?
6. What will we do?

Lecture slides and extended syllabus on hyperspectral imaging
Can be downloaded from [http://kho.unis.no](http://kho.unis.no) [under link Documents points 40) and 41)].
21 different institutions from 10 nations are present (2016).
Instruments @ KHO

**TELESCOPE**

**SPECTROMETERS**

**SPECTROGRAPHS**

**INTERFEROMETERS**

**CAMERAS**

**PHOTOMETERS**

**IN ADDITION**

a) Magnetometers  
b) Scintillation receivers (GPS)  
c) Riometer  
d) Weather station  
e) Web cameras
**AURORA**
Upper edge, rare (600-800 km)

**AIRGLOW**

![Image of aurora and satellite]

**COLLISION**

**SYNTHETIC OH(6-2) SPECTRUM T = 204 K**

![Graph showing intensity vs. wavelength with peaks at 367 Å and 844 Å]

**TEMPERATURE [K]**

![Graph showing temperature vs. year from 1978 to 2006]

**OTHER:**

\[ e_p + M_2 \rightarrow M_2^* \rightarrow e_p + M_2 + h_\nu \]

\[ e_p + M_2 \rightarrow M_2^{**} + e_p + h_\nu \rightarrow M_2^* + h_\nu + e_p + e_p \]

\[ M_2 \in \text{N}_2 \]

**WAVELENGTH [Å]**

6500 6600 6700 6800 6900

**NIGHTSIDE**

O:O2(0,1) N2(0,0) OI(3,0)
Basic optics (2D)

\[
\frac{1}{f_1} = \frac{1}{p} + \frac{1}{q}
\]

Object

Lens 1

Image

Optical axis

\( f_1 = \text{focal length} \)
Basic spectroscopy (2D)

The result is a prism spectrograph.

We could call it a pinhole color separator. It images the pinhole as a function of wavelength (color).

\[ n_p \sin \omega = \sin \alpha \]

\[ n_p = A_1 + \frac{B_1}{\lambda^2} \]
The result is a Grating spectrograph. It diffracts opposite in color compared to the prism spectrograph.

\[ n\lambda = a \sin \alpha + \sin \beta \]
Basic spectroscopy – We use a slit instead of pinhole (3D)

Hg 435.8 nm  Hg 546.1 nm

\[ \lambda \approx a \times px + b \]

Range = [355 – 720 nm]

SOURCE:
White paper illuminated by regular OSRAM low pressure gas discharge tube (office lamp).

Sodium Doublet
Na 589/589.6 nm.
Bandpass ~ 1nm
Spectrometers - Spectrographs @ KHO

Custom made instruments (MNOK)
Hyperspectral imaging (2D)

We now have an image in the entrance slit plane of the spectrograph. But only a slice of this image is allowed to enter. This slit image slice is now seen as a function of color in the exit plane. This will create structure in the spectrogram in the parallel direction of the slit.
Hyperspectral imaging (3D)

Image technique

In order to sample the whole Target object, we need to rotate the instrument or fly over it.

Or the slit entrance image needs to sweep across the entrance slit plane (rotating mirror).

This is known as the pushbroom technique.

The net result is a spectral cube or spectral movie.

We can now generate images as a function of wavelength.

It is hyper!
Pushbroom basics – Spatial resolution

Our instruments:
\[ w = 0.025 \text{ mm} \]
\[ h = 3 \text{ mm} \]
\[ f_1 = 16 \text{ mm} \]

Note that
\[ v \cdot \tau \leq dx \]

Table 1. Example calculations.

<table>
<thead>
<tr>
<th>Z</th>
<th>dx</th>
<th>Δx</th>
<th>SW</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.16</td>
<td>0.36</td>
<td>18.75</td>
</tr>
<tr>
<td>300</td>
<td>0.47</td>
<td>0.67</td>
<td>56.25</td>
</tr>
<tr>
<td>500</td>
<td>0.78</td>
<td>0.98</td>
<td>93.75</td>
</tr>
<tr>
<td>1000</td>
<td>1.56</td>
<td>1.80</td>
<td>187.5</td>
</tr>
</tbody>
</table>

**Table 1. Example calculations.**
Parameters: \( \Delta t = 20 \text{ ms \ (1/50) s.} \), 25 frames per second, read out time \( \tau = 20 \text{ ms} \) and speed \( v = 10 \text{ m/s (36 km/t)} \). All numbers in meters.
$$B_\lambda = \frac{M_o\lambda}{\pi} \rho_\lambda \left( \frac{z_o}{z} \right)^2 \times \cos \alpha$$
Spectral camera calibration

1. Lambertian screen
2. Rails
3. Movable trolley
4. Spectrograph
5. Baffle
6. Room lights
7. FEL tungsten lamp
SCENARIO
1. SVALSAT is well established.
2. All polar satellites in field of view.
3. Longyearbyen airport.
4. Local airborne carriers.
5. AGF-207, AGF-331 & AGF-218
6. Logistics
7. CryoWing UAV w/ NORUT IT

= REMOTE SENSING
AGF-331
Remote Sensing and Spectroscopy (15 ECTS)

Hyperspectral Students 2000 - 2007

AIRSPEX2007
DATA SAMPLES AIRSPEX (1999 – 2007)

AIRSPEX 2004
HYPERSONTRAL IMAGING
OCean COLOR NY-ÅLESUND

(a) 390 nm
(b) 405 nm
(c) 420 nm
(d) 450 nm
(e) 480 nm
(f) 510 nm
(g) 540 nm
(h) 570 nm
(i) 600 nm
(j) 630 nm
(k) 660 nm
(l) 690 nm

[450 – 570] nm
RGB [630, 570, 480] nm
Bayes Classification
AIRSPEX 2006

S2Pro DSLR

RGB 625, 550, 475 nm Longyearbyen, May 3, 2006 1500m

NIR 800, 625, 550 nm

Classification

(A) S2Pro DSLR,  (B) Webcam,  (C) Hyperspectral imager,  (D) Gyro / INS & (E) Battery pack
NEW TYPE OF INSTRUMENT DEVELOPMENT

EXAMPLE 1: HYPERSPECTRAL IMAGER

- Purchase optics and mounts
- EMCCD Andor Luca R
NEW TYPE OF INSTRUMENT DEVELOPMENT

EXAMPLE 2: no. 1 Meridian Imaging Svalbard Spectrograph (noMISS)

eMachineShop Parts

Tunable GRISM

Assemble optics and mounts (Thorlabs). Detector ATIK 314L+
KEY OPTICAL ELEMENT

The grating equation is modified by using Snell’s law

\[ m \lambda = a (n \sin \alpha + \sin \beta) \]

where \( m \) is the spectral order, \( \lambda \) is the wavelength, \( a \) the groove spacing, \( \alpha \) the incident angle and \( \beta \) the diffracted angle. \( n \) is the refractive index of the prism given by the formula of Cauchy

\[ n = A + \frac{B}{\lambda^2} \]

\( A \) and \( B \) are constants according to substance of the glass material used.

<table>
<thead>
<tr>
<th>Wavelength ( \lambda ) [nm]</th>
<th>Refractive index ( n )</th>
<th>Diffracted angle ( \beta ) [deg.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>1.61829</td>
<td>38.9872</td>
</tr>
<tr>
<td>400</td>
<td>1.58942</td>
<td>33.6908</td>
</tr>
<tr>
<td>500</td>
<td>1.57606</td>
<td>29.2111</td>
</tr>
<tr>
<td>600</td>
<td>1.56880</td>
<td>25.1126</td>
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<tr>
<td>700</td>
<td>1.56442</td>
<td>21.2360</td>
</tr>
<tr>
<td>800</td>
<td>1.56158</td>
<td>17.5051</td>
</tr>
<tr>
<td>900</td>
<td>1.55963</td>
<td>13.8757</td>
</tr>
</tbody>
</table>

Diffracted angles for a GRISM with \( \phi = \alpha = 30^\circ \), grating groove spacing \( a = 1666.667 \) nm (a 600 lines / mm) and spectral order \( m = 1 \).

Cauchy’s index of refraction constants are \( A = 1.5523 \) and \( B = 5939.39 \) nm for Borate flint glass.

The total spread in the diffracted angles of the spectrum is also less than using a grating alone. The latter is due to the fact that a prism disperses blue light more than red, whereas the grating diffracts red light more than blue.
NEW TYPE OF INSTRUMENTS

EXAMPLE 3: no. 1 NORUSCA

Liquid Crystal Tunable Filters (LCTFs).

Based on the Lyot filter (stack of birefringent plates).

“The ability to electronically tune the band pass wavelength of these filters throughout the visible electromagnetic spectrum makes them an ideal candidate for hyperspectral imaging”

Cost: 1 MNOK
NEW TYPE OF INSTRUMENTS

EXAMPLE 4: Narrow field of view Hyperspectral LCTF camera

Prototype hyperspectral camera: (1) lens, (2) Liquid Crystal Tunable Filter (LCTF)- Varispec, (3) aimpoint, (4) radio controller of camera head, and (5) Astrovid camera head.

Gyro rig: (1) mount arm, (2) elastic rope, (3) lens, (4) aimpoint, (5) Varispec filter, (6) camera head, and (7) hand held gyro stabilizer.

Snapshot of moon at 650 nm

Note that stabilization did not work airborne!
LOW COST DEVELOPMENT < 50 kNOK

Motivation
1. It now cost less to buy a drone than hiring an airplane or helicopter for one hour.

2. Low cost camera system with stabilization has been developed for and by the RC community.

3. New high sensitive detectors available (Surveillance, astrophysics, auroral, RC …).

4. 3D printing makes prototyping instruments
   a) low cost, ref point 1.
   b) low weight / mass.
   c) small size.
   d) fast …
LOW COST DEVELOPMENT < 50 kNOK

Mini spectrograph basic equations

Quadrocopter hyperspectral imager

\[ f_1/\# = \frac{d_1}{D_1} = 2.5 \]

\[ f_2/\# = \frac{f_2}{D_0 + D_1 + D_2} = \frac{f_2}{D_1 + 2D_0} = \frac{f_2}{D_1 + 2 \tan \beta} = \frac{f_2}{D_1 + 0.2 \beta} \]

Ex: \( \beta = 5 \) \( \Rightarrow \) \( f_2/\# = \frac{f_2}{10} \)

\[ \#56-770 ES \]

\[ f_2 = 25 \text{m} \quad f_2/\# = 2.5 \]

\[ \beta \]

\[ D_1 = 10 \]

\[ D_0 = D_2 \Rightarrow \tan \beta = D_0 / \beta \]

\[ d_0 = 13.8865 \quad d_1 = 19.3598 \quad d_2 = 24.8345 \]

\[ \beta = \beta_1 - \beta_0 = 5.474 \]

\[ \beta = \beta_2 - \beta_1 = 5.453 \]

\[ D_0 = D_2 \Rightarrow \tan \beta = D_0 / \beta \]

\[ \lambda - \text{Transmission grating } 12.7 \times 12.7 \text{ mm}^2 \]

ES #

J. Sørensen, October 2013
LOW COST DEVELOPMENT < 50 kNOK

Mini spectrograph Slit-Collimator assembly

All parts are from the mix and match assembly from Edmund Optics.
LOW COST DEVELOPMENT < 50 kNOK

Mini spectrograph Grating holder / Detector / Camera Clip on mount

Camera head
Turnigy PAL 700 TVL HobbyKing.com
Sony 1/3-Inch Super HAD CCD

Collector lens
ES 25mm f/2.5

Snapshot TINKERCAD freeware compatible with MakerBot 3D printer. Software is web based!
LOW COST DEVELOPMENT < 50 kNOK

Assembled Hybrid mini pushbroom hyperspectral imager

Micro lens hyperspectral imager
Mass = 106 g
Spectral range: VIS
Grating: 600 lines/mm
Slit width: 25um
Slit height: 3 mm
Front lens: 3.6 mm
Aperture: 10 mm
Collimator: 30 mm
Camera lens: 25 mm
CCD: 1/3" Sony Super HAD
OUTPUT: Video (PAL)
INPUT: 6-18V DC

Drone Experiment

Instrument mounted to a DJI F450 Quadcopter.

Note that the Gimbal here is brush type servos connected to the NASA-M flight controller.

The experiment was not successful due to vibrations and slow response of the gimbal.

We will do the same with hopefully a better brushless gimbal and carrier.