Handheld spectral imager for remote sensing, food quality and medical applications

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Motivation and Outline

To present the design, calibration and application measurement results for a novel staring spectral camera for Visible (VIS) and Very Near Infrared (VNIR)

- Introduction and objectives of the hand-held VIS-VNIR spectral imager development
- Fabry-Perot Interferometer (FPI) and principle of spectral imaging based on it
- General requirements for staring VIS-VNIR (λ=400 – 1000 nm) spectral camera
- Case study 1 : Monitoring of wine leave health status
- Case study 2 : Spectral imaging in clinical processes especially brain surgery
- VIS-VNIR FPI spectral imager concept and design overview
- Calibration and spectral characterization results
- Application measurement results & analysis status
- State-of-the-art in multi&hyperspectral imaging
- Conclusions
Introduction and objectives of the hand-held VIS-VNIR spectral imager development 1(2)

- Spectral imaging is a powerful tool in many applications. It combines conventional imaging and spectral measurements providing both spatial and spectral information on a target.
- Spectral imaging instruments however, have a tendency to be expensive and therefore they are presently used only in few medical and industrial applications.
- Recent progress in multispectral imaging based on mosaic filters (Ocean Optics, Silios etc.) enables the development of handheld, low cost multispectral imagers and in cases in which few known spectral bands provide adequate information on the target these imagers provide cost effective solution.
- In life science, food quality and safety, agriculture, process analysis technology, environmental monitoring and many other applications the imaging at few spectral bands does not provide the needed information and spectral imaging is required.
Introduction and objectives of the hand-held hyperspectral imager development 2(2)

- The first objective of the hand-held VIS-VNIR spectral imager development has been to assess the possibilities to make an instrument that can used in the whole VIS-VNIR wavelength range (400 – 1000 nm) and which can be easily adapted to different object sizes and distances when used similarly to a standard digital still camera.
- The second goal has been to study the performance of the built spectral camera in the agriculture, medical imaging and food quality monitoring applications.
Fabry-Perot Interferometer (FPI) and principle of hyperspectral imaging based on it

The Fabry-Perot Interferometer based hyperspectral imager concept.
Matching three Fabry-Perot Interferometer orders to a color image sensor R-, G-, and B-pixels

Transmission of the Fabry-Perot Interferometer at air gap value of 1100 nm

Combined Quantum efficiency of the Fabry-Perot Interferometer at air gap 1100 nm and the CMOS RGB image sensor MT009V022
The wider use of hyperspectral imaging has been blocked by the size and cost level of the available equipment.

The starting point for our development has been to find out whether it is possible to make a hyperspectral imager which would operate like a digital still camera.

In this case the imaging field of view and object distance could be altered by changing the objective lens and the spectral data cube could be stored to a memory in less than one second.

The other important development driver has been the possibility of the hyperspectral imager to be mounted as easily as a digital still camera.
General requirements 2(2)

The major general requirements are

- The system must operate like a digital still camera
- The wavelength range shall be 400 – 1000 nm and the spectral resolution < 10 nm @ FWHM
- The image resolution must be at least Wide-VGA (480 x 750 pixels)
- The system must be compatible with laptop control via USB2 port
- The spectral data cube must be processed and saved in the ENVI standard data format
Hyperspectral imaging of the monitoring of Wine leave health status

- Wine grapes are robust plants that can live more than 100 years but, depending on the atmospheric conditions, they may be attacked by several different plagues or diseases along their lives, or even by hailstorms. And all these problems affect in different ways to the quality of the grapes growing on those wines and, consequently in the long run, to the wine.

- Spectral imaging experiments were planned to detect Mildew on Wine leaves

- Downy Mildew is a disease that can be extremely serious in grapes and will cause severe crop loss. The fungus Plasmopara viticola causes downy mildew.
MEDI-IMAGING project

- MEDI-IMAGING - Infrared and spectral imaging in medical processes
- Funded by Tekes and companies
- Research partners:
  - University of Eastern Finland (Joensuu and Kuopio)
  - Department of Neurosurgery at Kuopio University Hospital
  - VTT Photonic devices and measurement solutions
Background for optical measurements in medical applications

Benefits of Optical methods

- Non-contact, non-destructive
- Fast (hundreds of samples per second)
- Measure "real" thing (no sampling errors)
- Easy to install and suitable for clinical measurements
- Robustness of clinical instruments → easy maintenance

Infrared imaging applications

- Oncology (breast, skin, etc.)
- Vascular disorders (diabetes DVT, etc.)
- Surgery
- Monitoring the efficacy of drugs and therapy
- Respiratory disorders (for example SARS)
- Tissue viability

Areas of usage:

- Temperature measurements
- Spectral measurements
- Clinical testing
- Fast thermal imaging
Case 2: Spectral imaging in clinical processes especially brain surgery 1(2)

Cedip IR camera

Brain tumour surgery under mouth-controlled operating microscope

5-ALA given 3h before surgery is changed into fluorescent porphyrin in malignant glioma that becomes red under 375 - 440 nm illumination with operation microscope (Zeiss Pentero)

Infrared thermal Image of deep vein Thrombphlebitus on the left leg


http://www.infraredcamerasinc.com
Case 2: Spectral imaging in clinical processes especially brain surgery 2(2)

- In the MEDI-IMAGING project Fabry-Perot Interferometer Spectral camera will be integrated to the Zeiss Pentero brain surgery microscope.
- The spectral range used in the study is 400 – 1000 nm.

The spectral camera is planned to be integrated to the Zeiss pentero brain surgery microscope at the Kuopio University Hospital.
Requirements originating from the Wine leave and brain surgery microscope applications

- Wavelength range: 400 – 1000 nm
- Spectral Resolution 7 – 10 nm @ FWHM
- Image resolution: scalable from 480x640 pixels to 5 Mpix
- Dynamic range: 12 bits
- Field-of-view: at least 30 degrees
- Imager controlled with a laptop via USB2 data link.
- 120 layer spectral data cube (5 nm spectral step) can be recorded in less than 5 s.
- Possibility to monitor image at a selected wavelength band in real time (In Brain surgery microscope)
Optical concept of the VIS-VNIR hand-held hyperspectral imager based on two RGB image sensors

- Optical design for 400 – 1000 nm hyperspectral imager utilizing two image sensors.
- The design uses a pair of standard achromatic lenses \( f = 35 \text{ mm} \), diam. = 25 mm and a commercial video objective (Kokagu 212371, focal length = 25.0 mm).
- In case 2: Ocular optics is replaced by the optics of Zeiss Pentero microscope.
Piezo Actuated Fabry-Perot Interferometer control electronics

[Diagram of the control electronics system with labels for V_ref, Ve, C_ref, C_m, V_sp, and set point voltage]
System block diagram of the VTT FPI VIS-VNIR Spectral Camera
Electronics modules of the VTT FPI VIS-VNIR Spectral Camera

- MT9P031-5Mp-sensor
  - RGB image sensor

- QUSB_10MB
  - Image acquisition

- 10MB-SRAM
  - Memory

- QUSB_10MB
  - Image acquisition
  - Control signals to C_CONTROLLER

- 10MB-SRAM
  - Memory

- Q-PP-FPI-herm
  - FPI module
  - Preamplifier

- C_CONTROLLER
  - Capacitance measurement
  - Piezo actuator control
VTT VIS-VNIR Spectral Camera SN006 for laboratory and field tests

- VTT has designed and built 2nd generation Spectral Camera prototype.
- Its performance specifications are:
  - Wavelength range: 400 – 1000 nm
  - Spectral Resolution 7 – 10 nm @ FWHM
  - Image resolution: scalable from 480x640 pixels to 5 Mpix
  - Dynamic range: 12 bits
  - Field-of-view: 30 degrees
  - Imager is controlled with a laptop via USB2 data link.
  - 120 layer spectral data cube (5 nm spectral step) can be recorded in less than 5 s.

VTT VIS-VNIR Spectral Camera SN006 prototype. The size of the electronics housing is 150 mm x 100 mm x 100 mm. The length of the optics tube is 130 mm.
Simulations of the two image sensor hyperspectral imager

- Simulated locations of the center wavelengths of the Fabry-Perot Interferometer pass bands at the FPI orders 2-8 as a function of the air gap between the mirrors. The FPI mirrors were assumed to be coated with 4 nm of Ti, 50 nm of Ag and 50 nm of SiO2.
VIS-VNIR Spectra Camera Calibration results – Wavelengths of the spectral peaks and spectral resolution as a function of FPI air gap

![Graph showing the relationship between air gap of the Fabry-Perot Interferometer and wavelength of the spectral peak, along with spectral resolution vs center wavelength for both the Visible Channel and NIR Channel.]
# FPI VIS-VNIR Hyperspectral Imager Performance Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral range</td>
<td>400 – 1000 nm Spectral range of VIS channel 400 – 650 nm NIR Channel 650 – 1000 nm</td>
</tr>
<tr>
<td>Spectral sampling step</td>
<td>1 nm The sampling is based on setting the air gap value.</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>7 – 10 (12) nm Measured spectral resolution @ FWHM for first device</td>
</tr>
<tr>
<td>Spectral Stability</td>
<td>&lt; 1 nm</td>
</tr>
<tr>
<td>Wavelength switching speed</td>
<td>&lt; 2 ms Settling time of the FPI air gap to a value</td>
</tr>
<tr>
<td>Incidence angle to FPI Cavity</td>
<td>&lt; 5° (max &lt; 7°) The spectral resolution and peak transmission depend on the beam angle</td>
</tr>
<tr>
<td>Average spectral transmission</td>
<td>&gt; 0.2 The spectral resolution and peak transmission depend on the beam angle</td>
</tr>
<tr>
<td>Image size</td>
<td>VGA to 5 Mpix CMOS sensor MT9P031. Image size can controlled by software</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>12 bit The dynamic range can be increased by addition</td>
</tr>
<tr>
<td>F-Number of the optics</td>
<td>2.8 – 5.6 Depending on the microscope objective</td>
</tr>
<tr>
<td>Focal length range of the optics</td>
<td>5 – 100 mm The ocular optics concept provides the possibility to use the imager as a digital still camera or C-Mount compatible videocamera.</td>
</tr>
<tr>
<td>Dimensions</td>
<td>50 mm x 65 mm x 120 mm Without the optics tube</td>
</tr>
<tr>
<td>Weight</td>
<td>&lt; 350 g</td>
</tr>
</tbody>
</table>
Test equipment:

- VTT Spectral Camera (spectral range: 400 – 1000 nm)
- A cork frame was used to hold reference samples
- Two tripods with rail were used to hold the cameras
Tests at Vineyard in Valencia district, Spain

- Tests were done on two days.
- The reference spectral images were taken by fixing the leaves on cork plate.
Classification of mildew used on calculations

- 0 (healthy)
- 1
- 2
- 3
- 4
Analysis of the reflection spectra of non-infected and infected leaf areas

- A preliminary analysis of the results has been performed but a comprehensive analysis will be done in coming months.

![Graph showing spectral reflectance data of non-infected and infected leaf areas.](image)

**Figure 1.** Spectral reflectance data of non-infected and infected wine tree leaf areas.
Status of integration of the spectral camera to the Zeiss Pentero brain surgery microscope in the MEDI-IMAGING project

- The FPI VIS-VNIR spectral camera has been integrated, calibrated and transferred to Kuopio.
- The integration of the spectral camera to the Zeiss Pentero brain surgery microscope will take place in November-December 2010.
State-of-the-art in multi&hyperspectral imaging

- New multispectral technologies are being developed by companies like Ocean Optics, Silios, etc.
- The Rotating Filter Wheel (RFW) Multispectral Camera technology has developed with small steps during recent years.
- The new opportunities is offered by the Dichroic Filter Array (DFA) Multispectral Camera technology presented by Ocean Optics at the SPIE conference “Imaging, Manipulation, and Analysis of Biomolecules, Cells, and Tissues VIII” SPIE Vol.7568.
- VTT has developed MEMS Fabry-Perot Interferometers for the visible wavelength range. This technology is planned to be used in the Finnish Aalto-1 nanosatellite for hyperspectral remote sensing.
- The combination of a MEMS FPI and a dichroic filter array would enable to build a hyperspectral imager whose spectral bands could be tuned to various applications.
Rotating Filter Wheel (RFW) Multispectral Camera

- Multispectral imaging has traditionally been performed with rotating filter wheel.
- If the wavelength bands required for the application are known the RFW multispectral imager is a straightforward solution.
- The disadvantages of the RFW concept are
  - Tuning of the spectral bands is not possible
  - The spectral bands are registered at different times
  - The miniaturization is challenging because of the filter wheel mechanism.

Dichroic Filter Array (DFA) Multispectral Camera

- The physical size of the DFA is 35 mm x 23 mm and there are 3500x2500 individual filters on the DFA. The pixel pitch is 10 μm x 10 μm.
- The image of a target is formed on the DFA surface and the Microscope objective forms an image of the DFA on the Camera sensor.
- The advantages of DFA camera are
  - The spectral bands are registered simultaneously
  - No moving parts
- The disadvantages of the DFA concept are
  - Tuning of the spectral bands is not possible
  - The miniaturization is challenging because of relay optics required for imaging the DFA to the image sensor.

Hyperspectral imager concept based on combining a Dichroic Filter Array with Fabry-Perot Interferometer

One can separate the multiple order peaks by using special filters!
Conclusions

- In the evaluation of the application requirements it was found that wavelength range of 400 – 1000 nm is adequate for most medical, food, agriculture and environmental spectral imaging purposes.
- A new low cost hand-held staring hyperspectral imager for applications previously blocked by high cost of the instrumentation has been built and characterized.
- The instrument can record 2D spatial images at several wavelength bands simultaneously.
- The benefits of the new device compared to AOTF or LCTF devices are small size, weight, speed of wavelength tuning, high optical throughput, independence of polarization state of incoming light and capability to record up to 5 wavelengths simultaneously.
- The prototype has been tried in the monitoring of wine leave health status and results are promising.
- A second spectral camera prototype is waiting to be integrated into Zeiss Pentero Brain surgery microscope and this camera will be used in measurements of the spectral properties of brain tissue.
VTT creates business from technology
UASI - SPEKTRIKUVANTAMISEN SOVELLUKSET KEVYESTÄ LENNOKISTA

Jyväskylän Yliopisto, Metla, MTT, VTT, JAMK
30.9.2010
Ismo Pellikka, Liisa Pesonen, Sakari Tuominen, Sirpa Thessler, Heikki Saari
(UASI, Unmanned Aerial System Innovations)
Additional Slides on proposed UASI – Unmanned Aerial System Innovations Project

- University of Jyväskylä, Coordinator
- VTT Photonic devices and measurement solutions
- MTT Agrifood Research Finland
- Finnish Forest Research Institute (Metla)
- Finnish Defense Forces
- Tornator Oy
- Metsähallitus, Forestry
- Millog Oy
- Pieneering Oy
- Suonentieto Oy
- TMI Jouko Kleemola
Preliminary Overview of agriculture UAS imaging service system

1. Image Acquisition
- Autopilot & modem
- VIS-VNIR Spectral Camera
- Hi-Res Camera

2. Image Processing
- Image products
  - 3D data
  - 2D maps
  - Spectral Data cube
  - 2D application specific spectral maps
- Pre-processing & registration software
- DTM processing software
- Spectral data processing software

3. Image Analysis
- Wine plant application processing software
- Forest inventory application processing software
- Precision agriculture application processing software
- Environment monitoring application processing software

Application products
- Vineyard disease & yield thematic maps
- Forest inventory maps
- Precision agriculture maps

Image product data for application product service
Application of spectral imaging in crop farming
- Information flow is marked with numbers

FARMER
Enchanted farming and production planning
- saves in fertilizer, watering & other costs
- Product quality > price
- Environmental issues

INDUSTRY
Forecasting and traceability data (contracts)
Amount and quality of crop yield

DATA FOR A FARM
Weather and other ambient env. data

WEB data bases for farmers data

INFORMATION SERVICES/ FARMING PROGRAMS
Spectral libraries for interpretation
Support for interpretation and farming planning
manual&automatic

FARMER INDUSTRY
Aerial images
Interpreted images
Planning maps
Actual maps

FARMING TASKS
- FERTILIZING
- SPRAYING

ADMINISTRATION
Knowledge on the validity of the EU support conditions
Application of spectral imaging in forestry applications - Information flow is marked with numbers

**Forest officer/Forest usage planner**

**Cutting planning**
- stand based tree volume and
- tree species data to PC
- More accurate cutting plan
  saving cost in cutting work

**WEB-DATABASES**

**Forest Remote Sensing data**

Aerial images
Interpreted images

**Stand based data**

**Cutting plan**

- Borders of the area to be cut
- Image data of the forest area
- Tree volume and species data

**Weather and other ambient env. data**

**Aerial images**

**Cutting of forest**

2.

3.

4.

5.

6.

**INDUSTRY**

Forecasting and traceability data (contracts)
amount, species and quality of cut trees

**INFORMATION SERVICES**

Interpretation + forest usage planning

**RESEARCH**

Spectral data bases

**ADMINISTRATION**

Knowledge on the validity of the EU support conditions

**1.**

**2.**

**3.**

**4.**

**5.**

**6.**