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

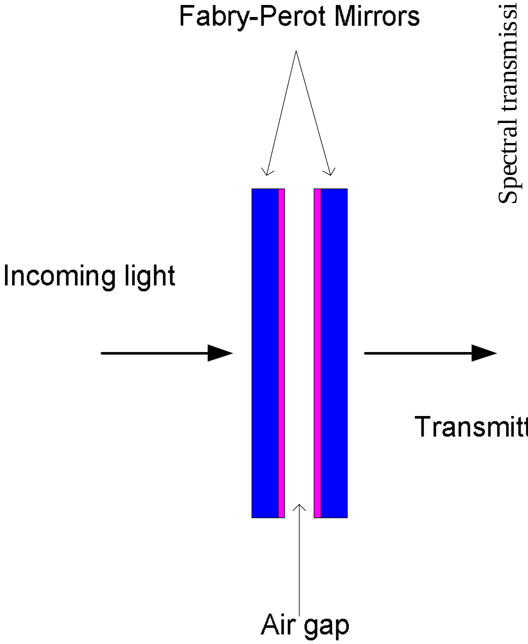
Introduction and objectives of the hand-held VIS-VNIR spectral imager development 1(2)

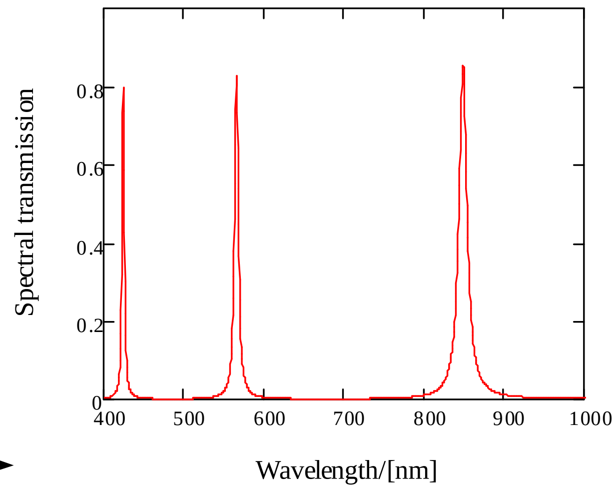
- Spectral imaging is a powerful tool in many applications. It combines conventional imaging and spectral measurements providing both spatial and spectral information on a target.
- Spectral imaging instruments however, have a tendency to be expensive and therefore they are presently used only in few 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.

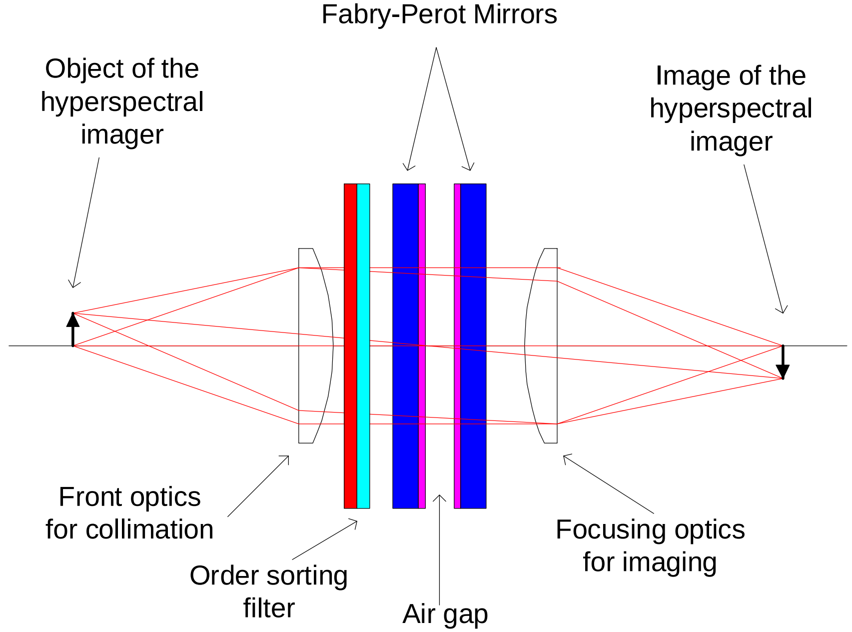
Introduction and objectives of the hand-held hyperspectral imager development 2(2)

- 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



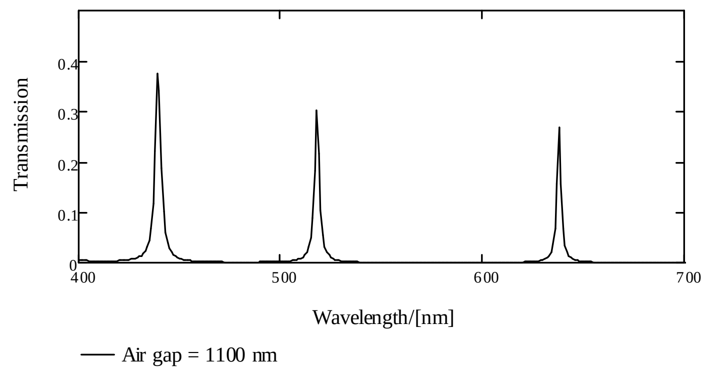




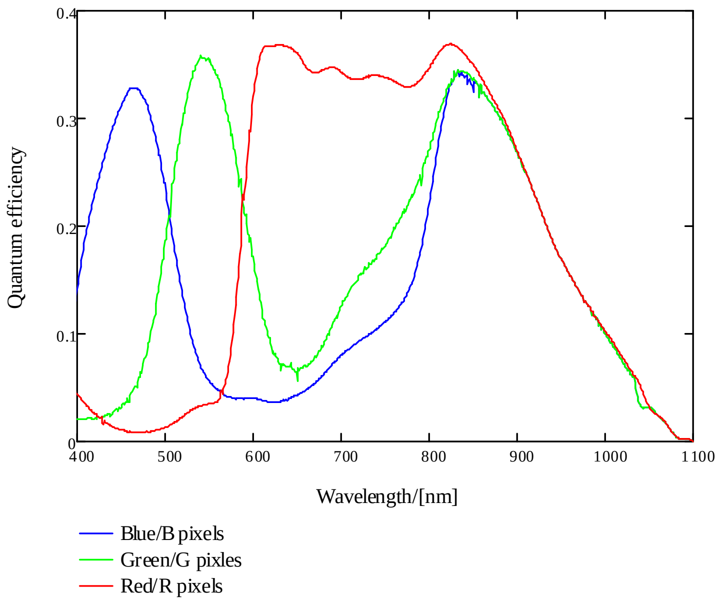
The Fabry-Perot Interferometer based hyperspectral imager concept.

Matching three Fabry-Perot Interferometer orders to a color image sensor R-, G-, and B-pixels

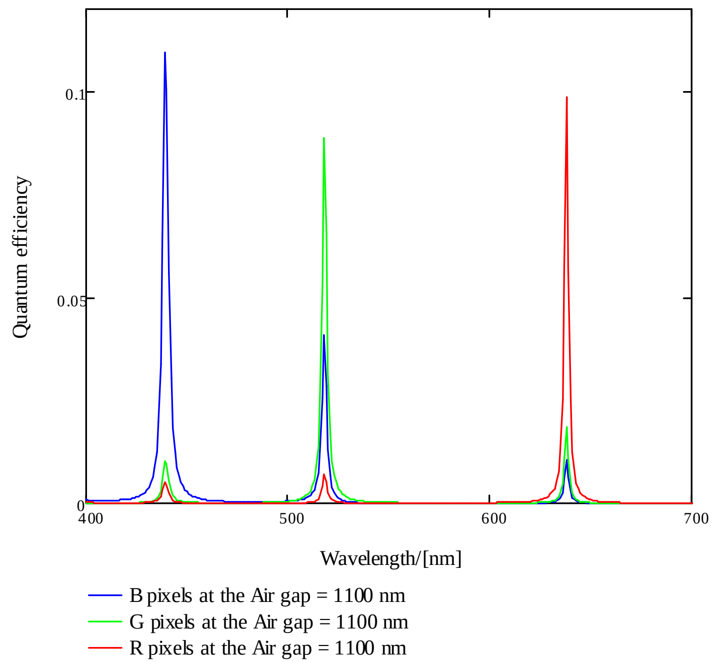
Transmission of the Fabry-Perot Interferometer at air gap value of 1100 nm



Quantum efficiency of CMOS RGB image sensor MT009V022



Combined Quantum efficiency of the Fabry-Perot Interferometer at air gap 1100 nm and the CMOS RGB image sensor MT009V022



General requirements 1(2)

- 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.

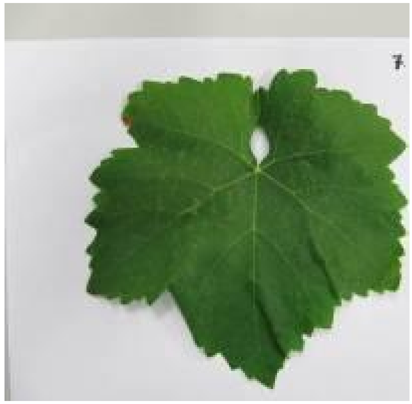
General requirements 2(2)

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

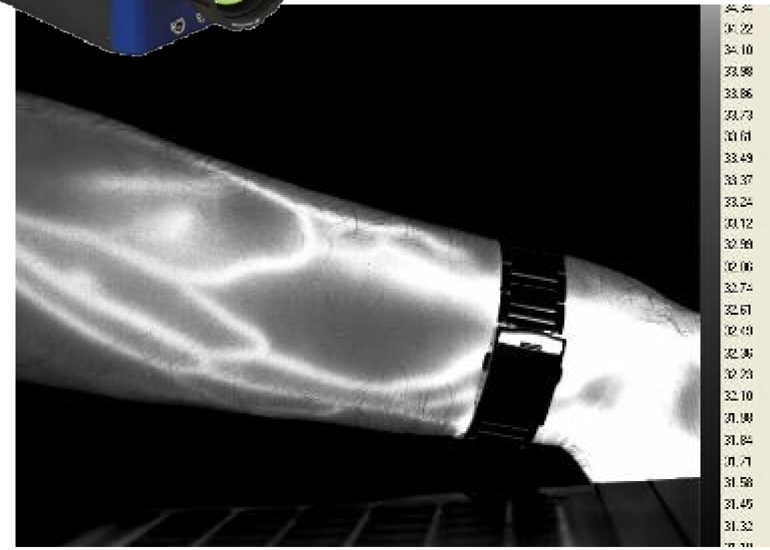
- Wine grapes are robust plants that can live more than 100 years but, depending on the atmospheric conditions, they may be attacked by several different plagues or diseases along their lives, or even by hailstorms. And all these problems affect in different ways to the quality of the grapes growing 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
- Schedule: 1.1.2010 – 31.12.2011
- 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

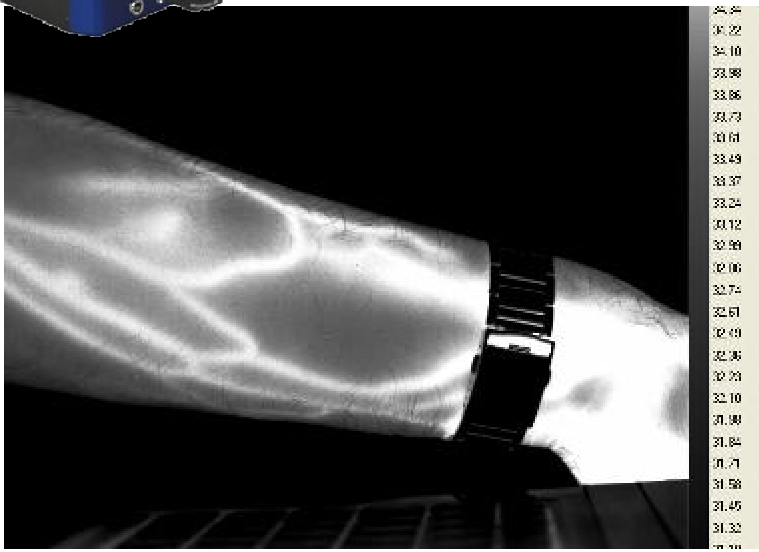
- Oncology (breast, skin, etc.)
- Vascular disorders (diabetes DVT, etc.)
- Surgery
- Monitoring the efficacy of drugs and therapy
- Respiratory disorders (for example SARS)
- Tissue viability

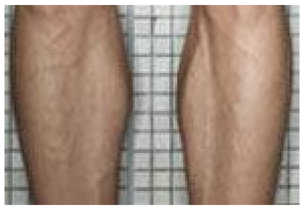
Areas of usage:

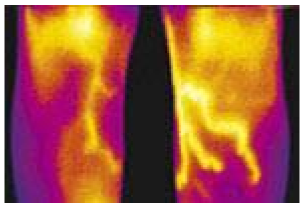
- Temperature measurements
- Spectral measurements
- Clinical testing
- Fast thermal imaging

Case 2: Spectral imaging in clinical processes especially brain surgery 1(2)

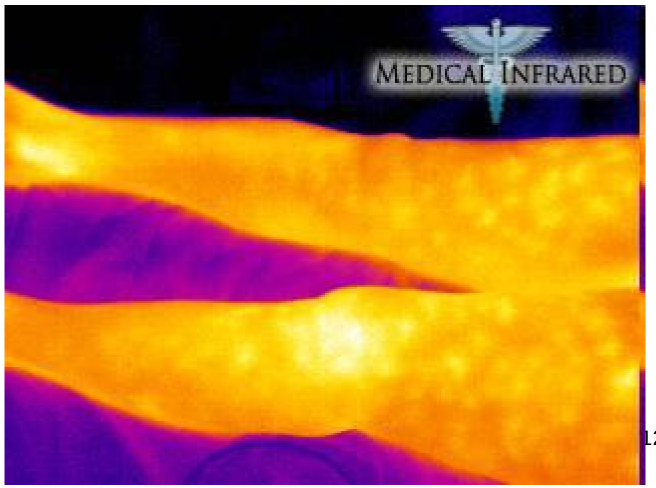
Cedip IR camera







http://www.flir.com/thermography/eurasia/en/



Infrared thermal Image of deep vein Thrombphlebitu 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 unique TRIO 620 is easy to attach

Ergonomics and freedom of movement are unchanged

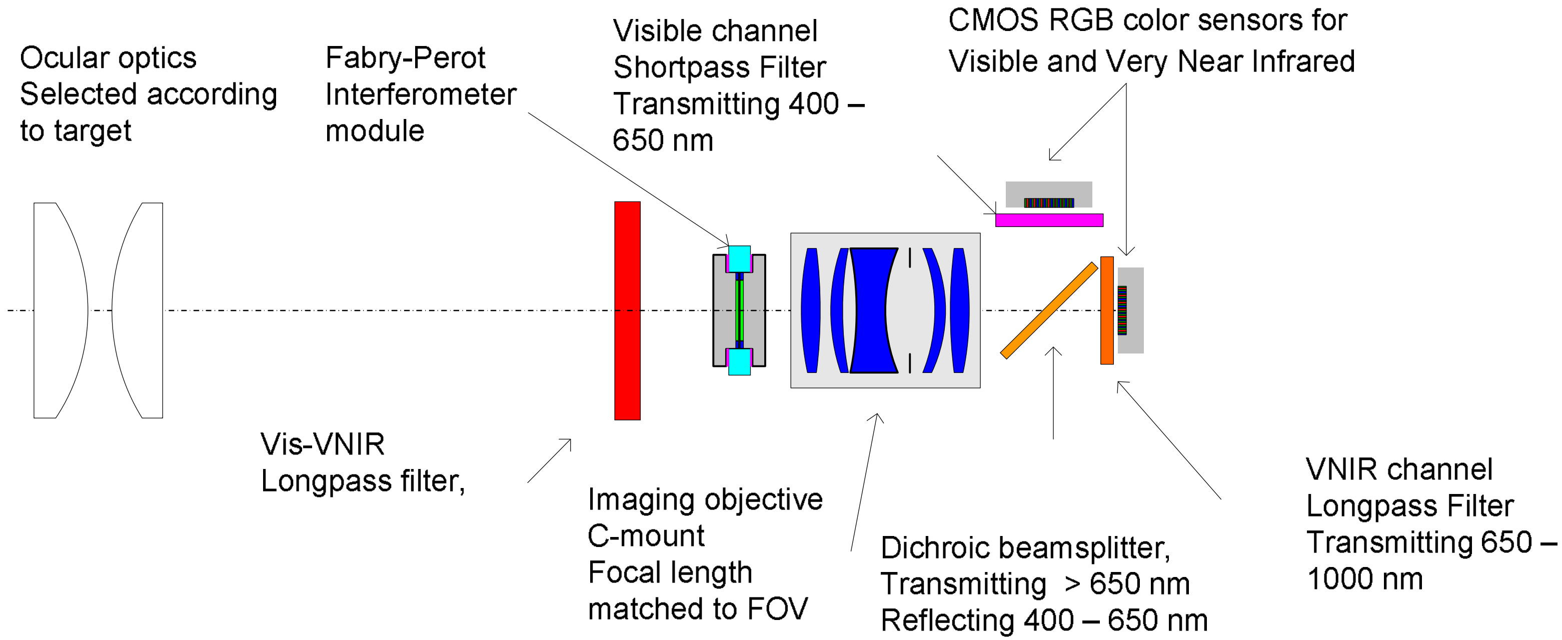
The spectral camera is planned to be integrated to the Zeiss pentero brain surgery microscope at the Kuopio University Hospital

Requirements originating from the Wine leave and brain surgery microscope applications

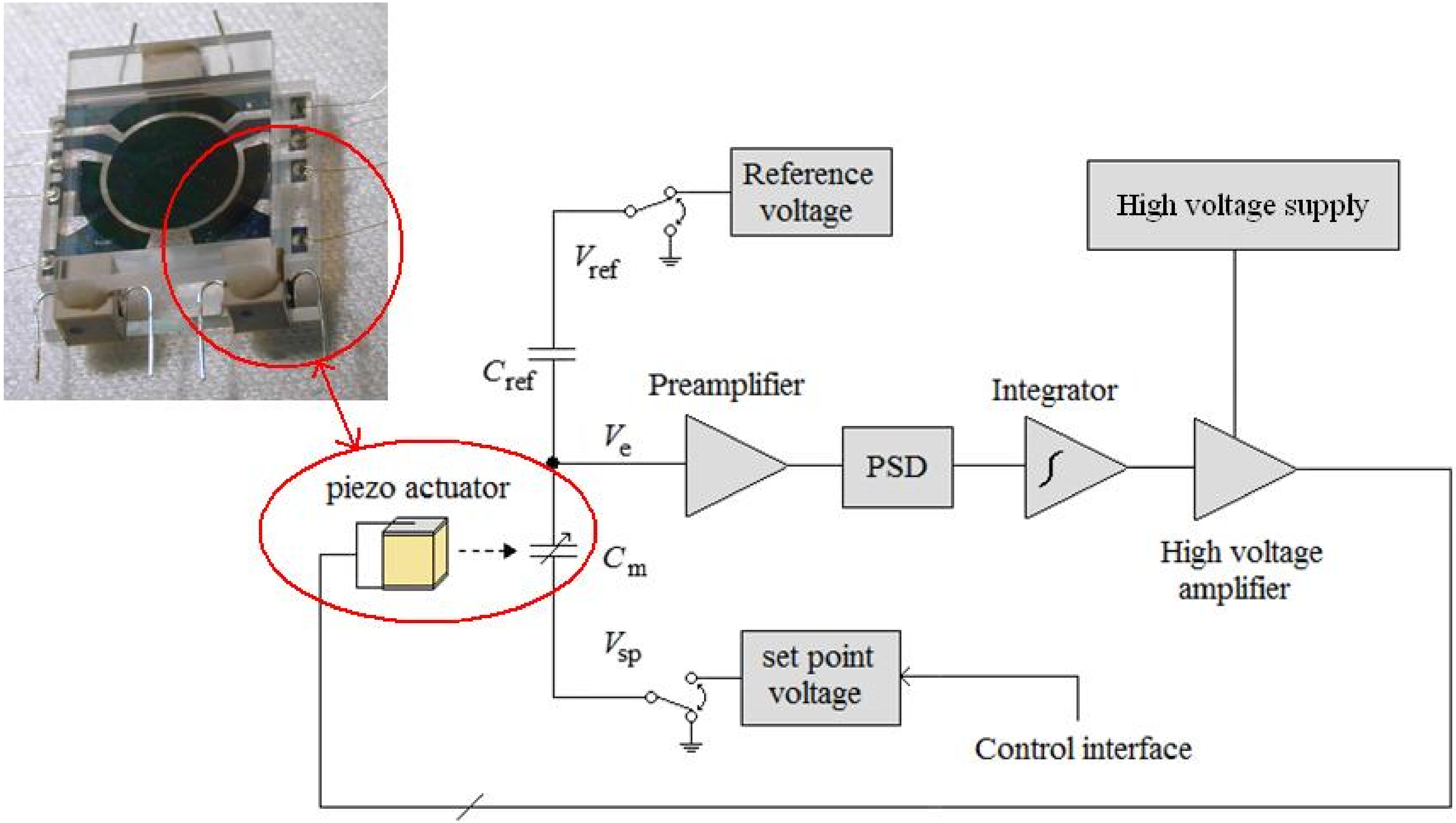
- Wavelength range: 400 – 1000 nm
- Spectral Resolution 7 – 10 nm @ FWHM
- Image resolution: scalable from 480x640 pixels to 5 Mpix
- Dynamic range: 12 bits
- Field-of-view: at least 30 degrees
- Imager controlled with a laptop via USB2 data link.
- 120 layer spectral data cube (5 nm spectral step) can 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

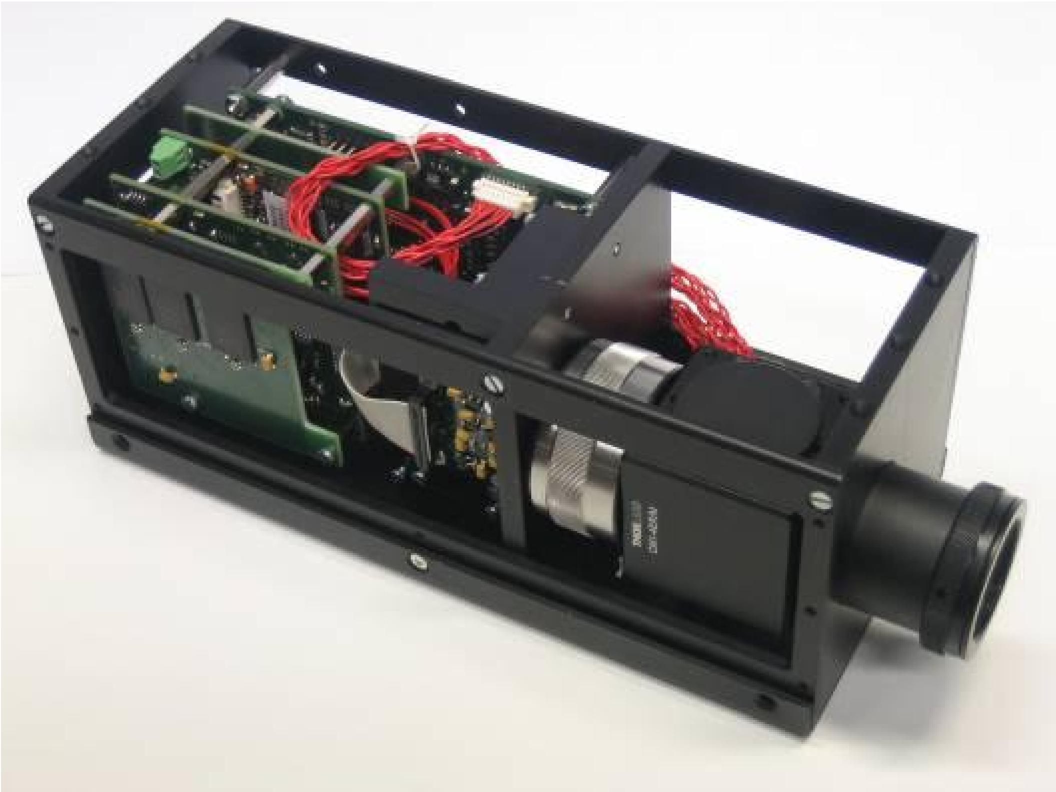
- **Optical design for 400 – 1000 nm hyperspectral imager utilizing two image sensors.**
- **The design uses a pair of standard achromatic lenses f = 35 mm, diam. = 25 mm and a commercial video objective (Kokagu 212371, focal length = 25.0 mm).**
- **In case 2: Ocular optics is replaced by the optics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

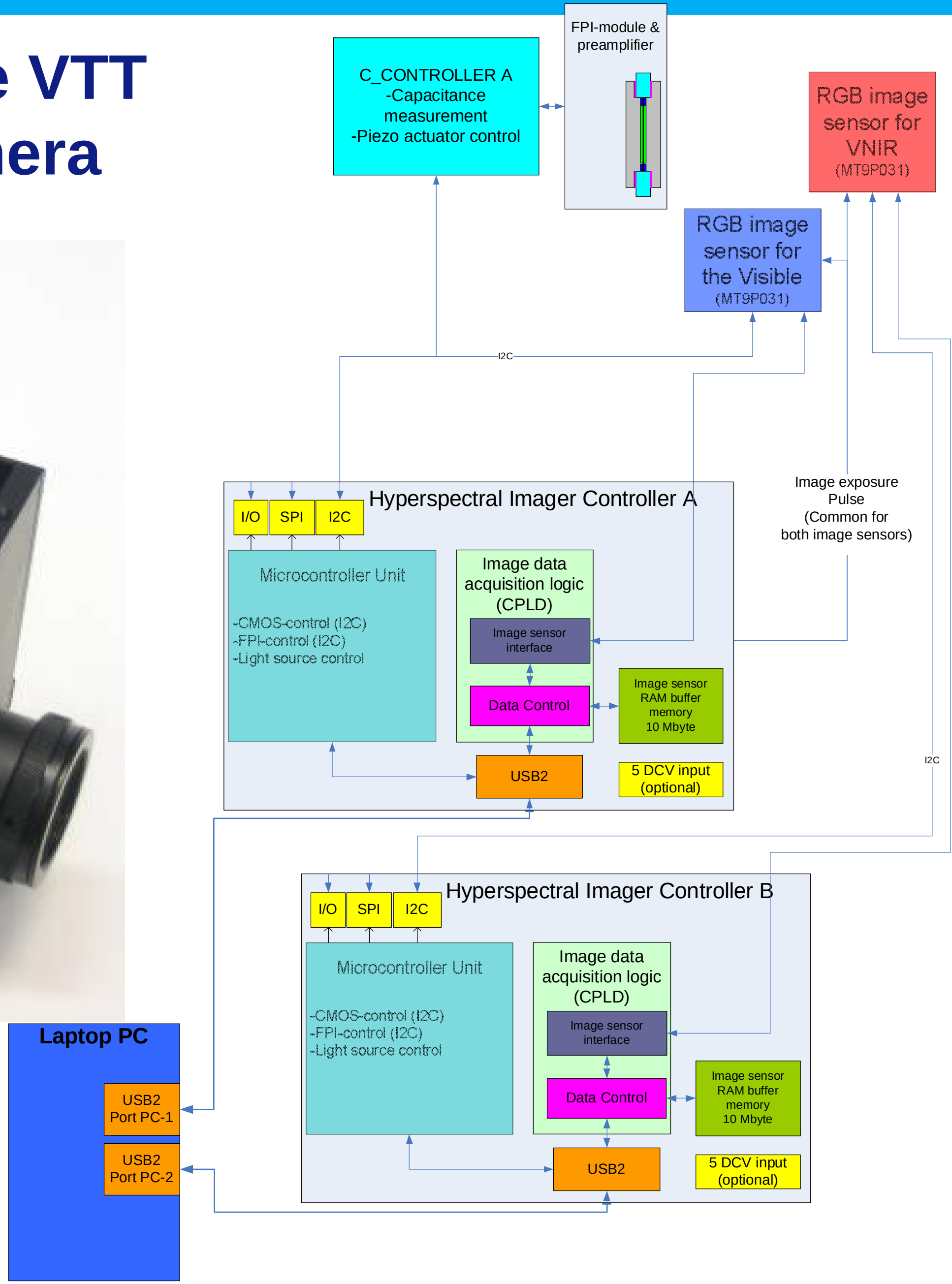


Piezo Actuated Fabry-Perot Interferometer control electronics



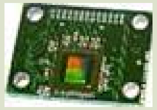
System block diagram of the VTT FPI VIS-VNIR Spectral Camera



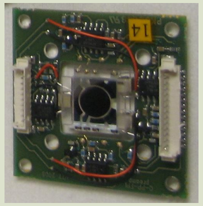


Electronics modules of the VTT FPI VIS-VNIR Spectral Camera

MT9P031-
5Mp-sensor
-RGB-image sensor



MT9P031-
5Mp-sensor
-RGB-image sensor



Q-PP-FPI-herm
-FPI-module
-preamplifier

QUSB_10MB
-Image acquisition

10MB-SRAM
-Memory

QUSB_10MB
-Image acquisition
-Control signals to
C_CONTROLLER

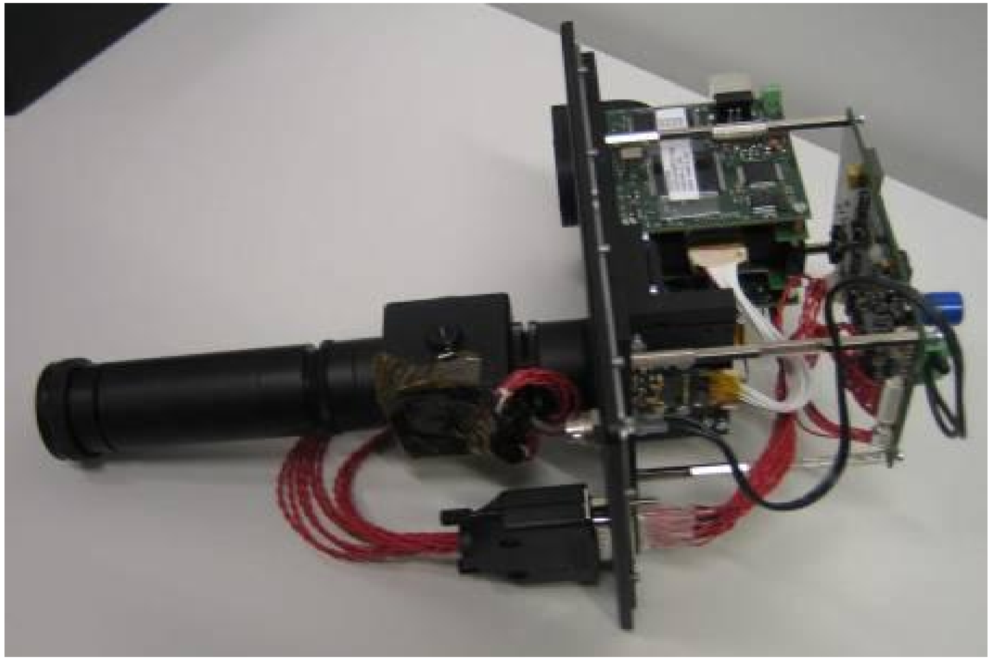
10MB-SRAM
-Memory

C_CONTROLLER

-Capacitance
measurement
-Piezo actuator
control

VTT VIS-VNIR Spectral Camera SN006 for laboratory and field tests

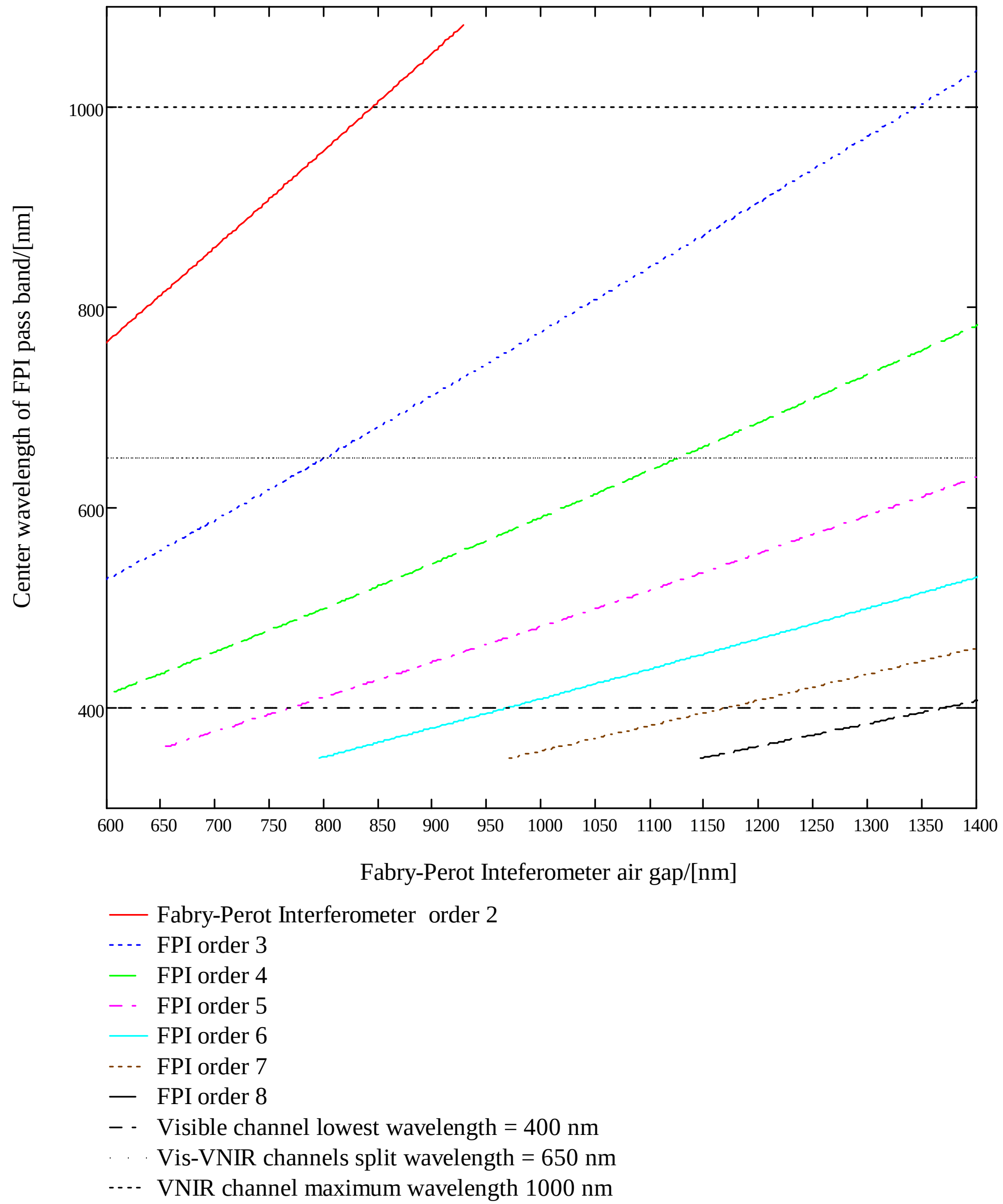
- VTT has designed and built 2nd generation Spectral Camera prototype.
- Its performance specifications are
  - Wavelength range: 400 – 1000 nm
  - Spectral Resolution 7 – 10 nm @ FWHM
  - Image resolution: scalable from 480x640 pixels to 5 Mpix
  - Dynamic range: 12 bits
  - Field-of-view: 30 degrees
  - 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.



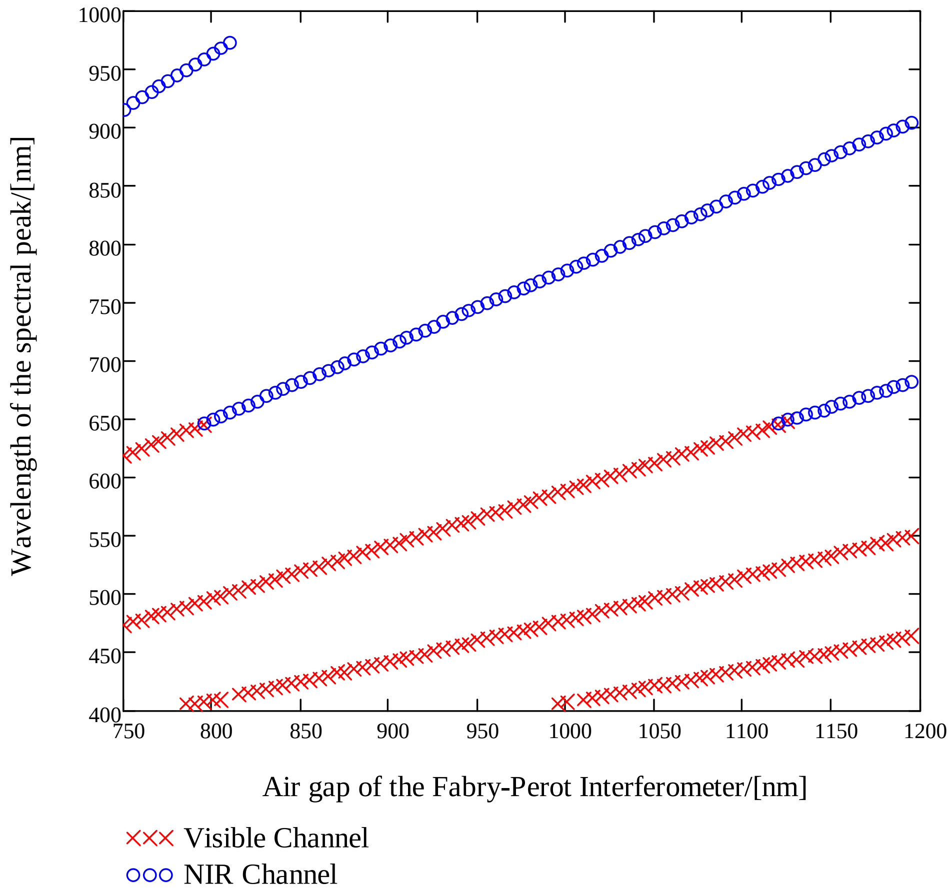
VTT VIS-VNIR Spectral Camera SN006 prototype. The size of the electronics housing is 150 mm x 100 mm x 100 mm. The length of the optics tube is 130 mm.

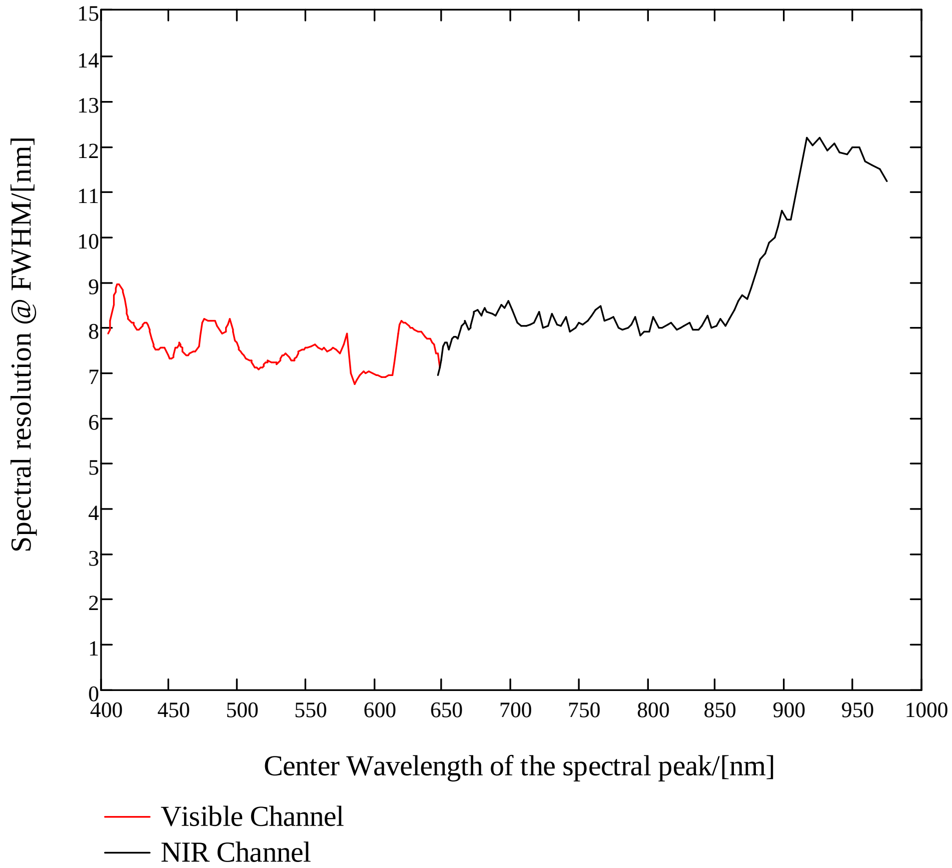
Simulations of the two image sensor hyperspectral imager

- 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





FPI VIS-VNIR Hyperspectral Imager Performance Summary

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

Tests at Vineyard in Valencia district, Spain

Test equipment:

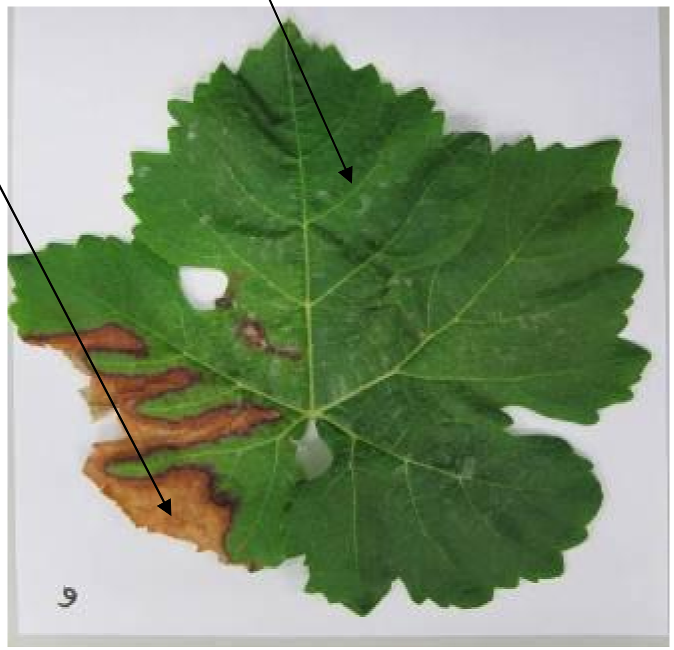
- VTT Spectral Camera (spectral range: 400 – 1000 nm)
- A cork frame was used to hold reference samples
- Two tripods with rail were used to hold the cameras

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.

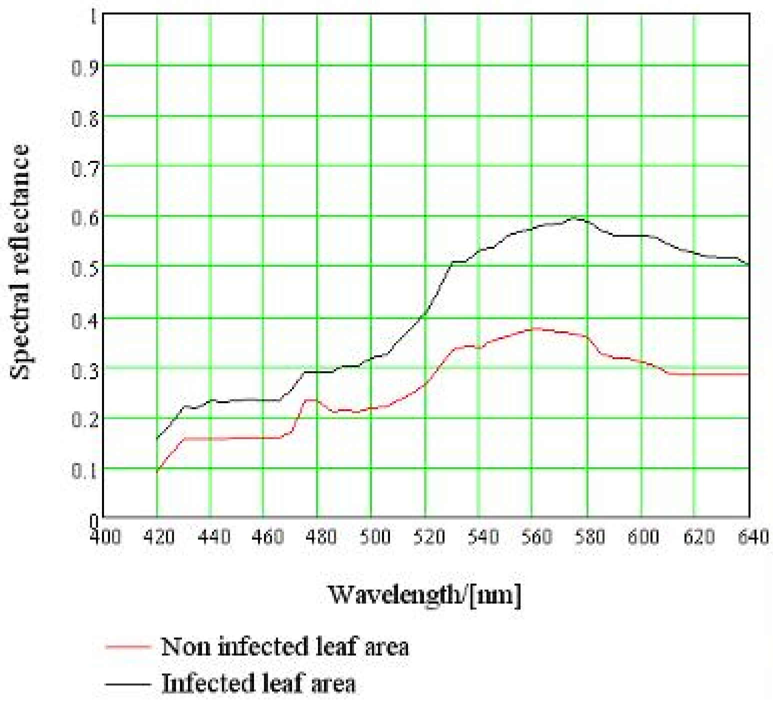
Classification of mildew used on calculations

- 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.



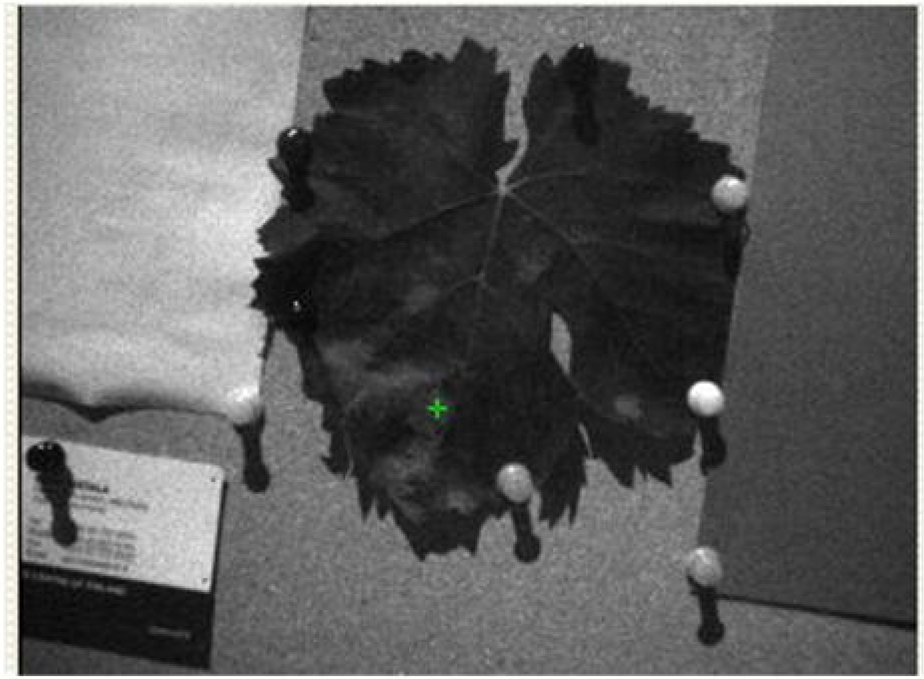


Figure 1. Spectral reflectance data of non-infected and infected wine tree leaf areas.

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 straight forward 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 challanging because of the filter wheel mechanism.

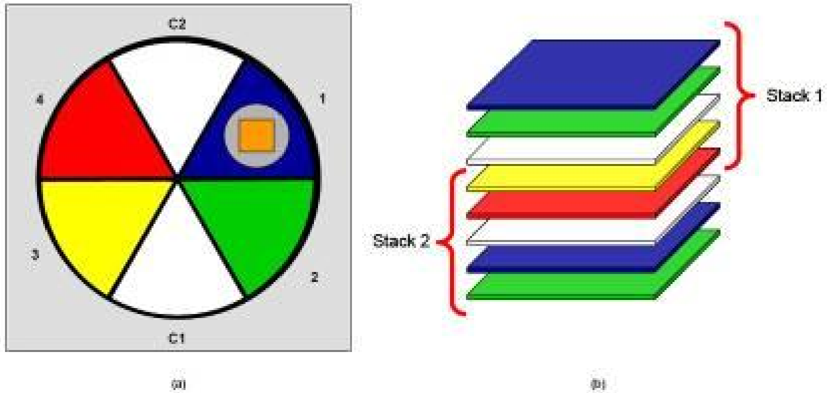


Figure 3. Rotation of the filter wheel and stacking of the data into the image stack for image stabilization and processing

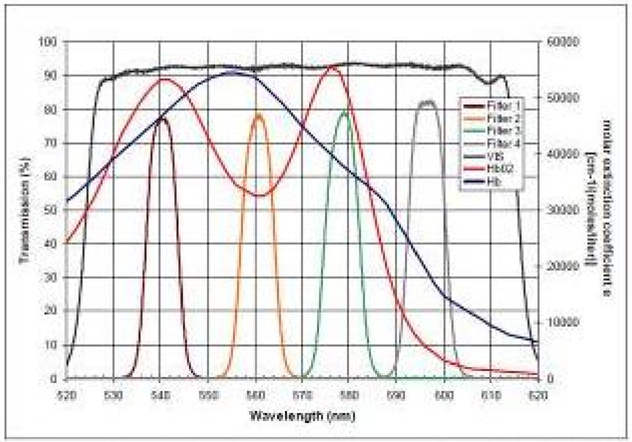
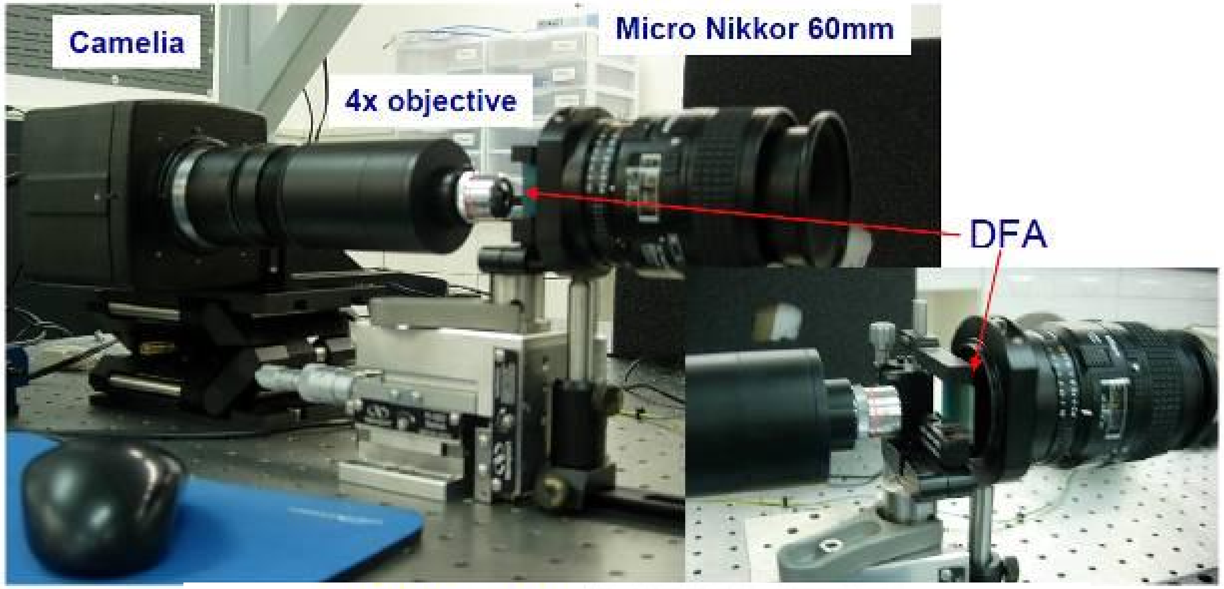


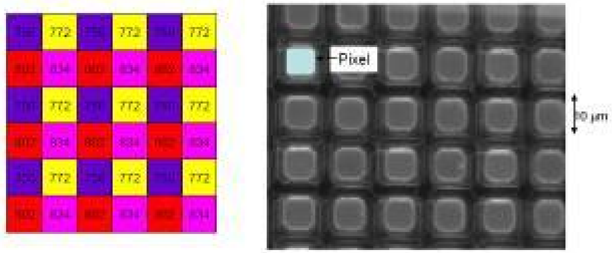
Figure 2. RFW pass bands overlaid with the key blood oxygenation curves of the initial application. Note the >75% pass band for the filters (Filter1-Filter4), as well as the visible blocking filter (VIS). Also shown are molar extinction curves in cm^{-1}/(moles/liter)

Ref. Eichenholz, J.M., et.al., “Real time Megapixel Multispectral Bioimaging”, Proc. SPIE 7568 (2010).

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.





(a) (b)

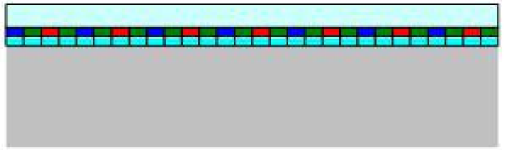
Figure 5. (a) Bayer like pattern and (b) microscope image of the dichroic filter array.

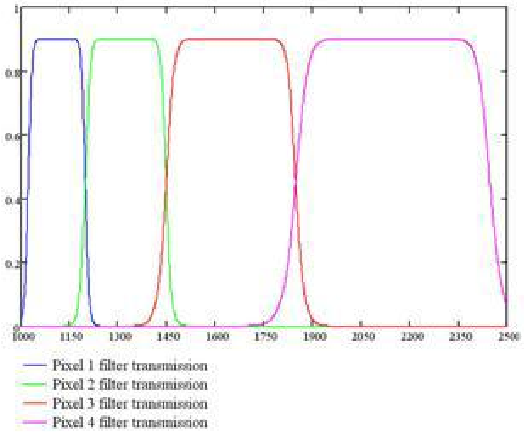
The physical size of the DFA is 35 mm x 23 mm. There are 8.75 Million (3500x2500) individual filters on each DFA. Each individual pixel is 10 µm x 10 µm on a 10 µm center to center spacing with a 1 micron border around the edge of each pixel resulting in an active area of 8 µm x 8 µm. A microscope transmission image of a small section of the DFA is shown above in Figure 5b.

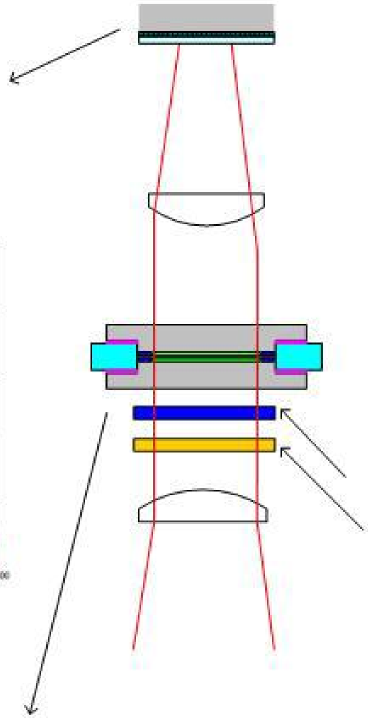
Ref. Eichenholz, J.M., et.al., “Real time Megapixel Multispectral Bioimaging”, Proc. SPIE 7568 (2010).

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

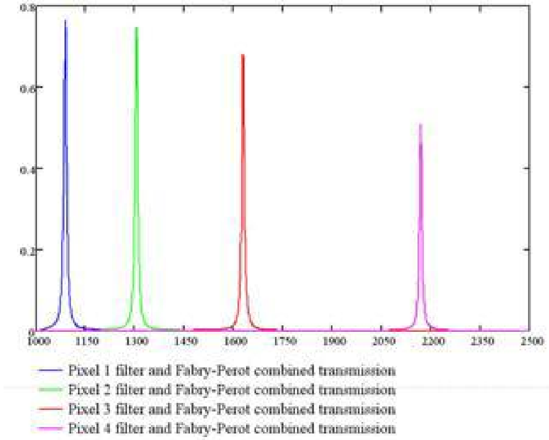
Patterned dielectric multispectral filter array integrated with a IR detector





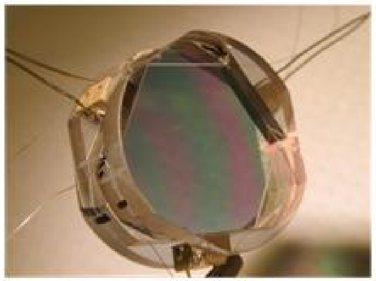


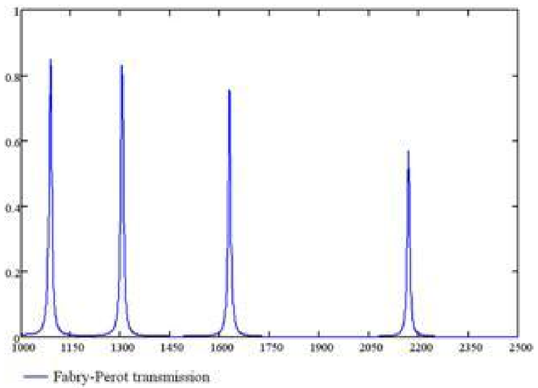
Combined spectral transmission of Patterned dielectric multispectral filter array and Fabry-Perot Interferometer used at 4 orders



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

Piezoactuated Fabry-Perot Interferometer module





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

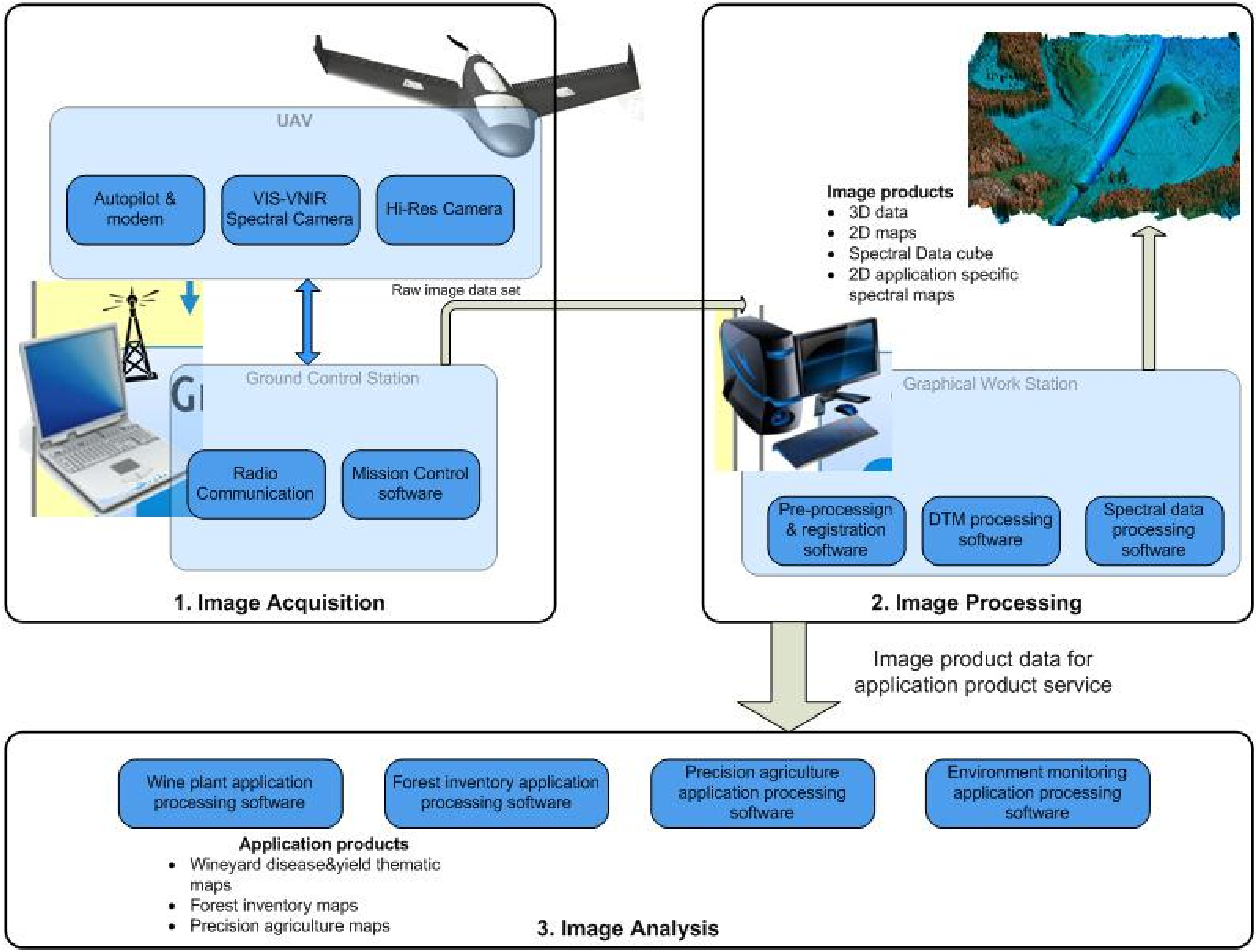
Ismo Pellikka, Liisa Pesonen, Sakari Tuominen, SirpaThessler, Heikki Saari

(UASI, Unmanned Aerial System Innovations)

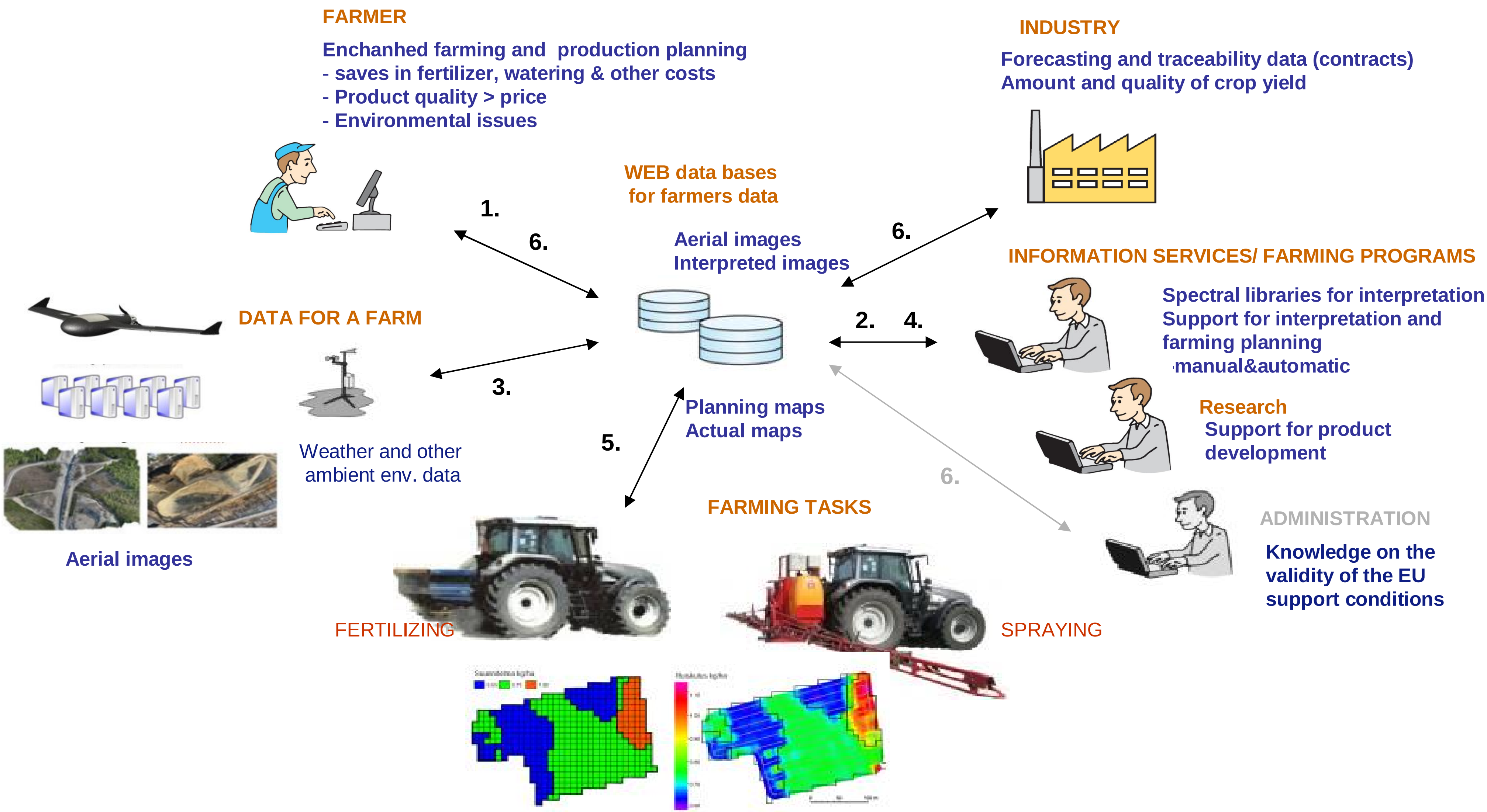
Additional Slides on proposed UASI – Unmanned Aerial System Innovations Project

- 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



Application of spectral imaging in crop farming - Information flow is marked with numbers



Application of spectral imaging in forestry applications- Information flow is marked with numbers