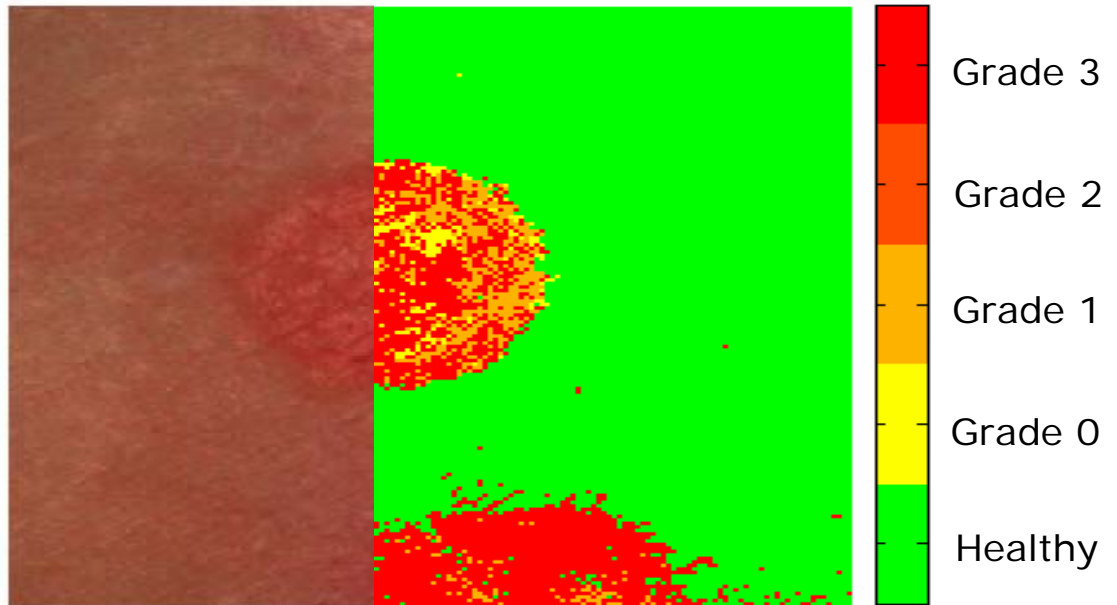


# *Spectral Imaging as a Modern Tool for Medical Diagnostics*

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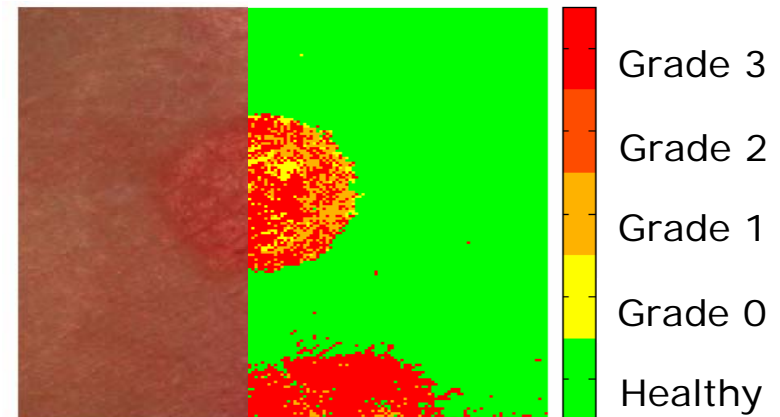
- **Spectral Imaging for Medical Applications**
- **Example: Spectral Imaging applied to Allergy Tests**
- **Acquisition of Hyperspectral Data**
- **Preprocessing and Feature Extraction**
- **Classifier Training and Testing**
- **Results**
- **Conclusion**

## ➤ Why should we use Spectral Imaging for Medical Applications ?

- Allows non-invasive and in-vitro investigations
- It's a purely optical method
- Hyperspectral data contain information about:
  - Colour, material, concentration, etc. (depending on wavelength range)
- Results can be visualised as intuitive (false-colour) images

## ➤ Medical Applications

- Skin cancer detection <sup>1</sup>
- Analysis of histological samples <sup>2</sup>
- **Allergy tests**
- Skin diseases (psoriasis, neurodermitis, etc.)
- Cosmetics (precise colour measurements, etc.)
- Blood measurements (oxygenation, etc.)
- ...



<sup>1</sup> D. L. Farkas, et al., Applications of Spectral Imaging: Detection and Analysis of Human Melanoma and Its Precursors, Pigment Cell Res 14: 2-8 (2001)

<sup>2</sup> G. Siboni, et al., Spectral Imaging of MC540 During Murine and Human Colon Carcinoma Cell Differentiation, Journal of Histochem. Cytochem 49: 147-153 (2001)

## ➤ Allergy Tests

- Many different symptoms => diagnosis difficult => skin tests
- Prick test or patch test
- Status quo: Diagnosis is done manually by physician
- **Non-invasive** and **in-vitro** method for automatic classification is required

## ➤ Proposed System

- Acquisition of hyperspectral data of affected skin portions
- Spectral Imaging Technology
- Visible Light (380-780nm)
- Hyperspectral classification of the skin reactions after the test

## ➤ Benefits

- Objective result obtained from chemometrical features
- Reduction of diagnosis effort (for the physician)
- Physician can concentrate on relevant results

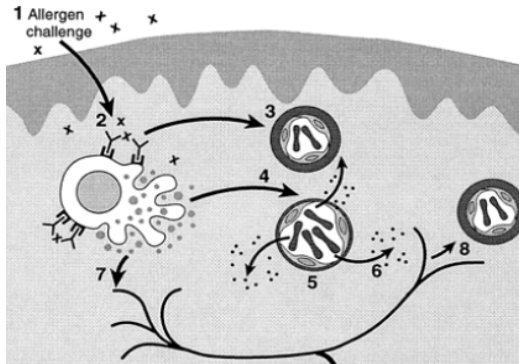
Prick test



Patch test



## Type 1 hypersensitivity (IgE<sup>2</sup> mediated)

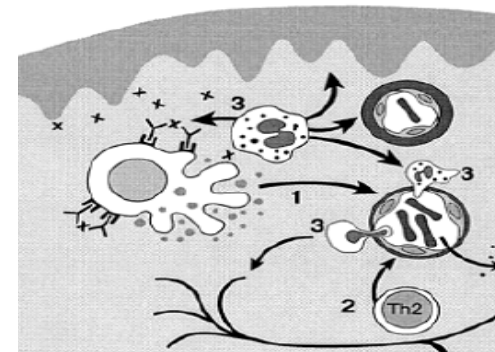


- 1-20 minutes after the exposure to the allergen
- The allergen interaction with IgE on the surface of mast cells triggers the release of inflammatory mediators

### Prick Test

- A small needle is used to gently prick the skin through a drop of fluid containing a known allergen.
- Positive reaction: erythema at skin around needle prick (itchy and red) with the development of a white swelling called a weal.
- Weal reaches its maximum size in about 15 to 20 minutes and the reaction fades within a few hours.

## Type 4 (delayed) hypersensitivity (contact dermatitis)



- Mast cells and Th2 cells (T lymphocytes) produce cytokines, which trigger further inflammatory cells from the periphery. This causes swelling and erythema (redness).

### Patch Test

- Taping traces of various known contact allergens (typically 20-30) on the skin and keeping them there for 48 hours. The test site is inspected 48 and 72 hours after application.
- Positive reaction: erythema, swelling, and vesiculation.

<sup>1</sup> Images reproduced from <http://www.immunology.unibe.ch>, Immunologie II, chapter 11, Sept. 2005

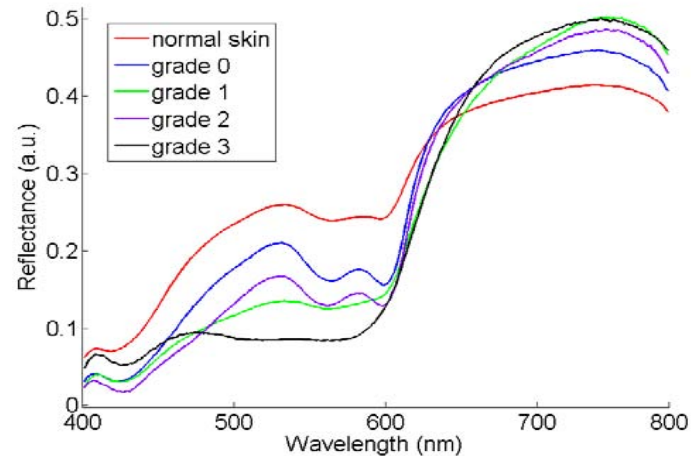
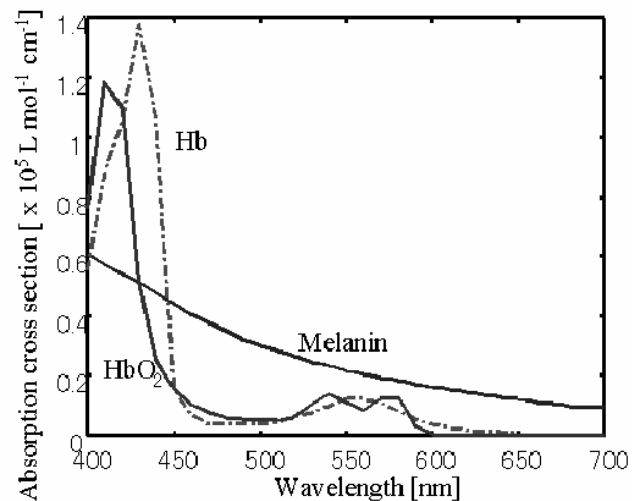
<sup>2</sup> Immunoglobulin E: One of five classes of immunoglobulins of humans (besides IgA, IgD, IgG and IgM)

## ➤ Skin Components

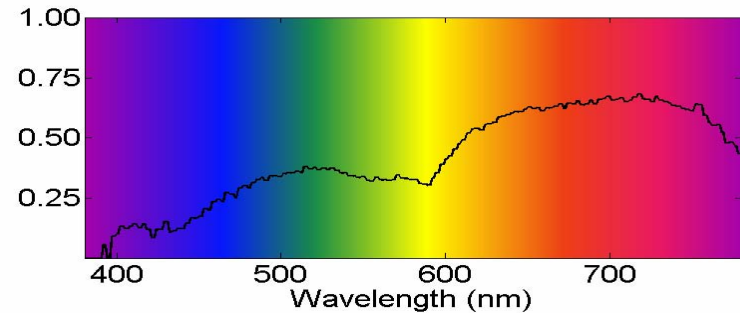
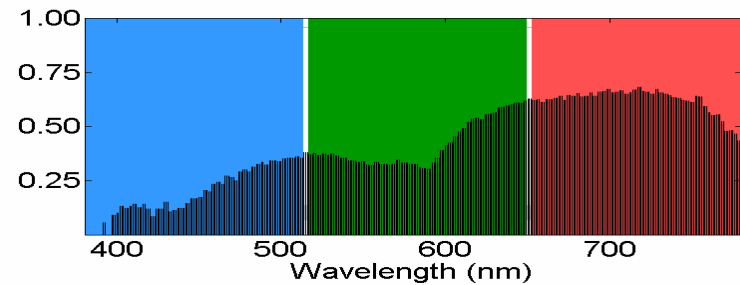
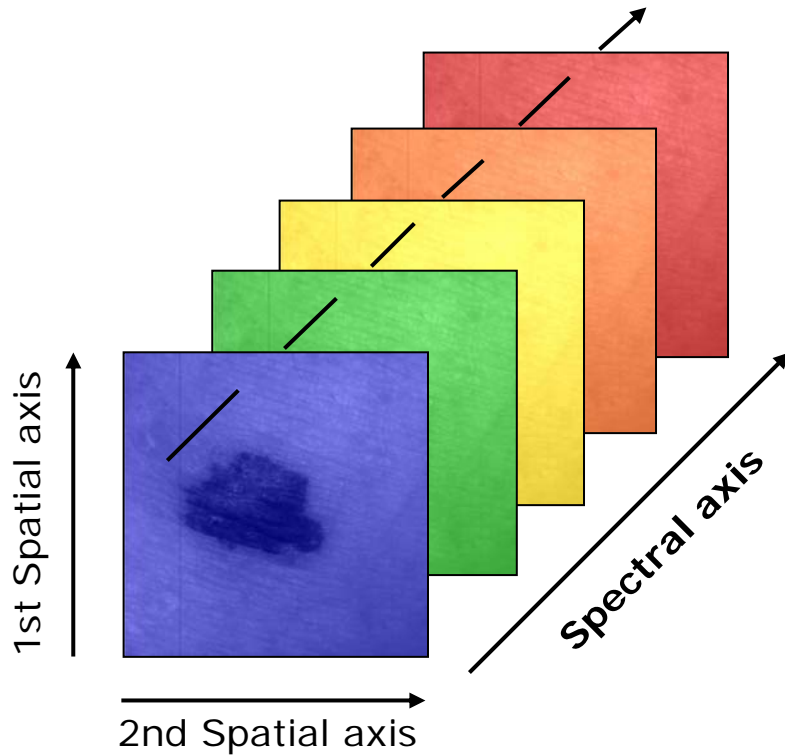
- Oxygenated hemoglobin
- Deoxygenated hemoglobin
- Melanin (pigmentation)

## ➤ Four different grades (after patch test)

- Grade 0: negative, no inflammation
- Grade 1: light inflammation, elevated
- Grade 2: medium inflammation, small pits
- Grade 3: intense inflammation with vesicles



Norimichi Tsumura, et. al, Mapping pigmentation in human skin by multivisible-spectral imaging by inverse optical scattering technique, Department of Information and Image Sciences, Chiba University, Chiba, Japan



## Spectral Imaging Data

- High spatial resolution
- High spectral resolution
- 3-dimensional data

## Acquisition of Spectral Imaging Data

- One spatial or spectral dimension over time
- Wavelength scanning
- *Push-broom* scanning (spatial scanning)

## ➤ Acquisition

- 2-dimensional, wavelength coded images
- Simultaneous: 1st and 2nd spatial axis
- Sequential: spectral axis

## ➤ Instrumentation

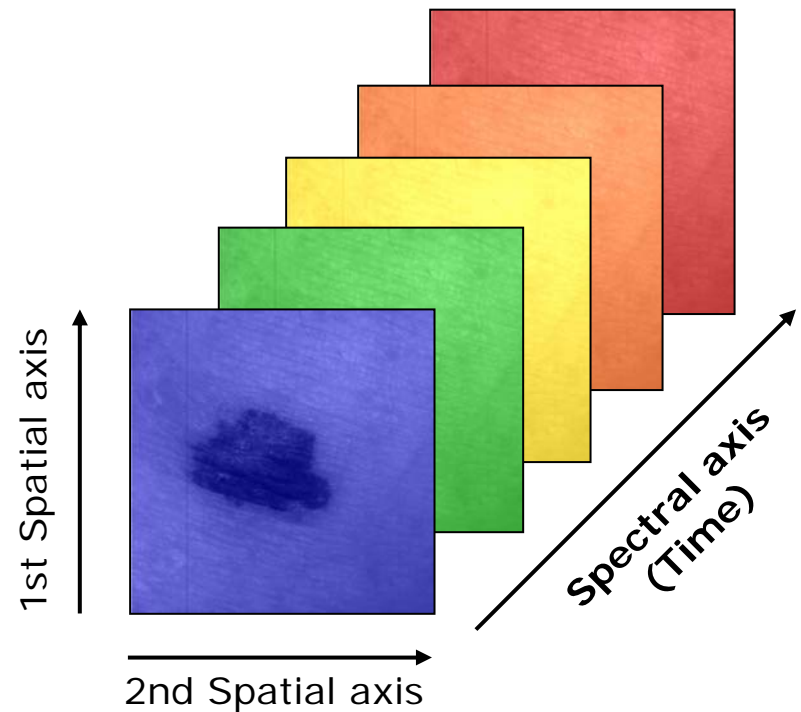
- Camera (CCD, CMOS, InGaAs)
- Filter wheel (up to ~8 wavelengths)
- Tunable Filter:
  - Acousto-optical tunable filter AOTF
  - Liquid-crystal tunable filter LCTF

## ➤ Advantages

- Simple and easy to use
- Filter instrumentation is relatively cheap

## ➤ Disadvantage

- Motion-artefacts corrupt spectra (= > stop-motion)





## ➤ Acquisition

- 1-dimensional images (lines) with spectral decomposition
- Simultaneous: 1st spatial axis + spectral axis
- Sequential: 2nd spatial axis

## ➤ Instrumentation

- Camera (CCD, CMOS, InGaAs)
- Linear-variable Filter
- Mikromirror array / grating - combination

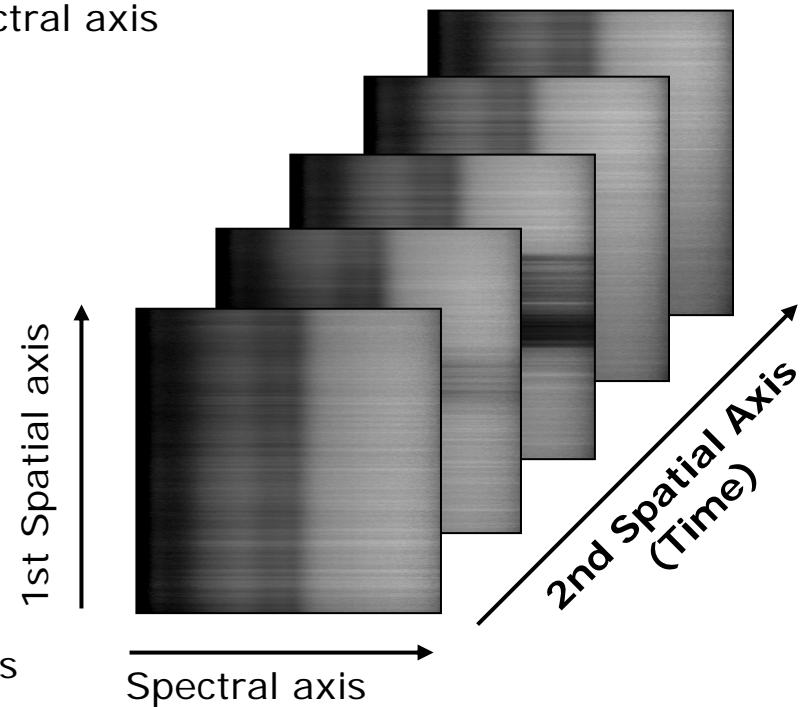
## ➤ Imaging Spectrograph

## ➤ Advantages

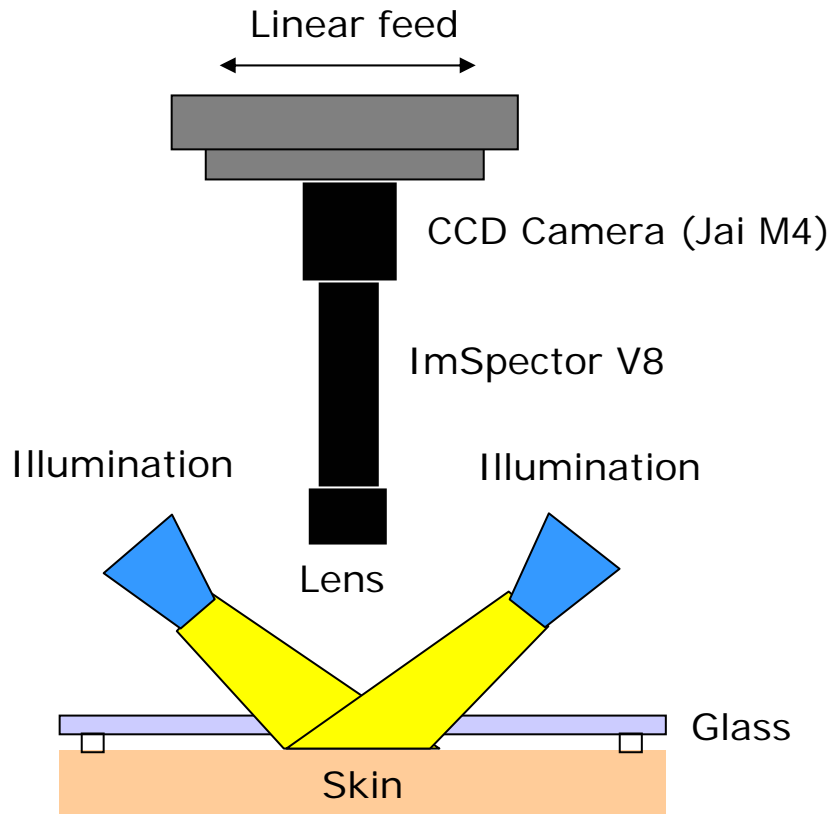
- Motion in 2nd spatial axis is compatible with existing transport direction (conveyor belt)
- Suitable for industrial systems and environments
- Spectral information is not corrupted by motion

## ➤ Disadvantage

- Generally more expensive than filter solutions

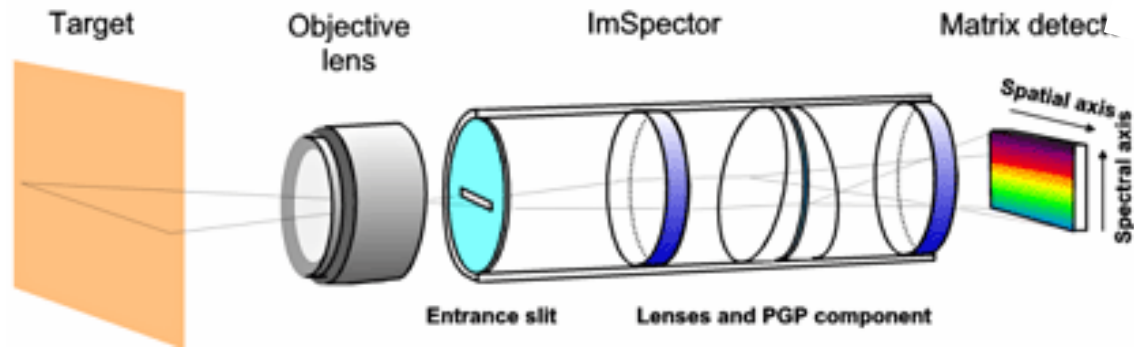


# Acquisition System (Prototype)

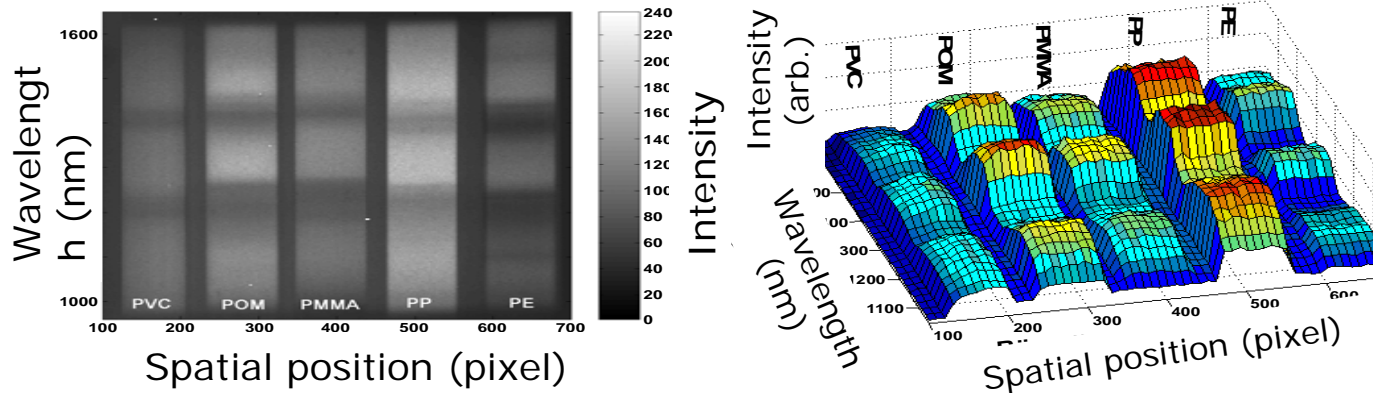


- Field of View: 40 x 40 mm
- Spatial Resolution: 100  $\mu\text{m}$
- Spectral Resolution: 13 nm
- Wavelength Range: 380 - 780nm

➤ **Imaging Spectrograph principle** (ImSpector®, Specim Ltd.)

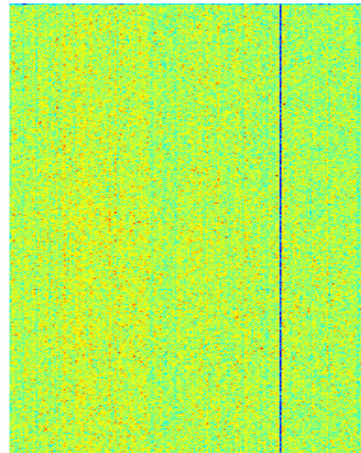


➤ **NIR „images“ of some technical polymers (1000-1700nm)**

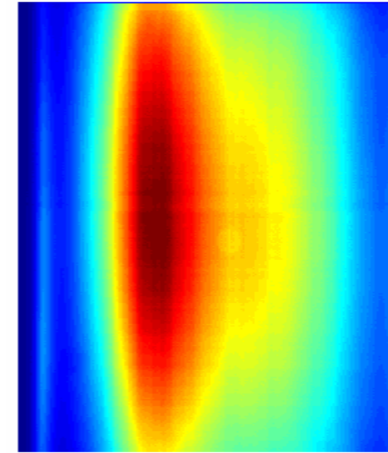


## ➤ Diffuse Reflectance

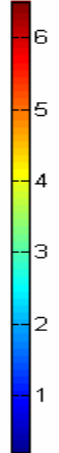
$$R(x, \lambda) = \frac{X(x, \lambda) - B(x, \lambda)}{W(x, \lambda) - B(x, \lambda)}$$



Black reference



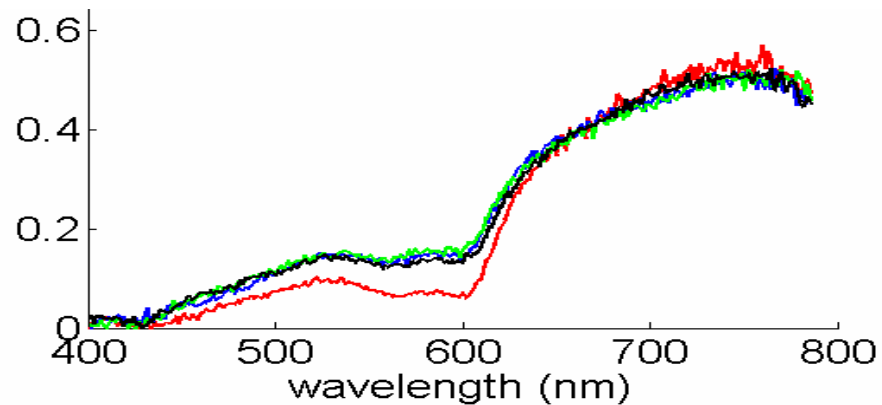
White reference



$10^4$

## ➤ Normalisation (L2)

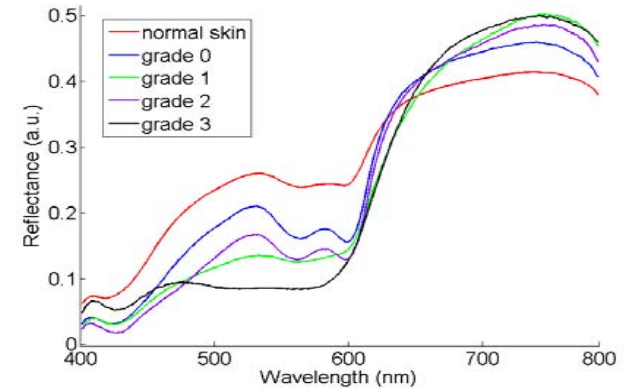
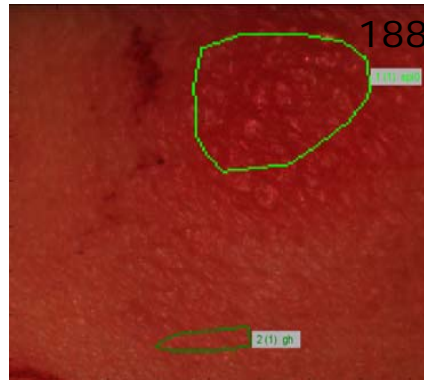
$$R(x, \lambda) = \frac{R(x, \lambda)}{\sqrt{\sum_{\lambda_i=1..n} R(x, \lambda_i)^2}}$$



## ➤ Patch test data set (manually labeled)

**Spatial Resolution:** 512x512  
**Spectral Resolution:** 270 bands

**Training set:** 8 cases  
**Test set:** 24 cases  
**Overall dataset:** 32 cases



## ➤ Feature Extraction

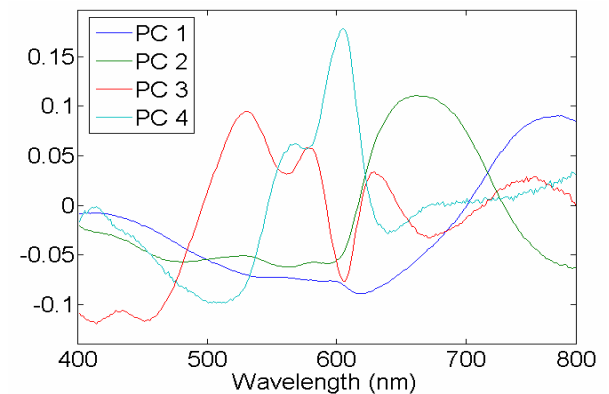
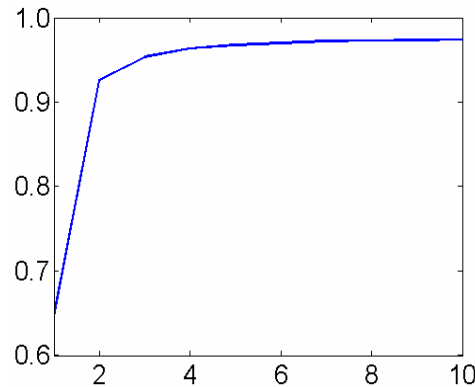
Spectra are high-dimensional and highly redundant features

Direct application of statistical classifiers difficult/impossible

Feature Extraction with PCA.

## ➤ Classifier Training

- QDA
- LDA



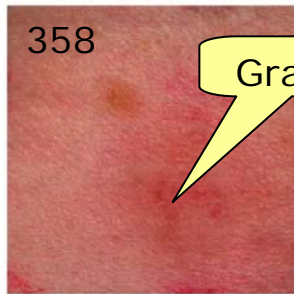
➤ **Results for 5 class problem (correct pixel/total pixel):**

Patch test result	QDA	LDA
Grade 0	81.6 %	74.2 %
Grade 1	65.3 %	88.0 %
Grade 2	79.4 %	66.3 %
Grade 3	85.1 %	77.4 %

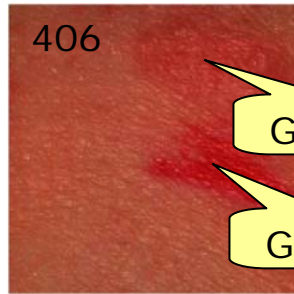
➤ **Results for 4 class problem (correct pixel/total pixel):**

Patch test result	QDA	LDA
Grade 0	81.6 %	74.2 %
Grade 1+2	87.3 %	82.5 %
Grade 3	85.1 %	77.4 %

# Patch Test Data - Classification Results (2)

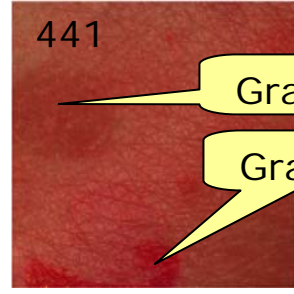


Grade 0



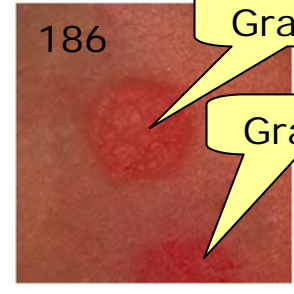
Grade 1

Grade 2



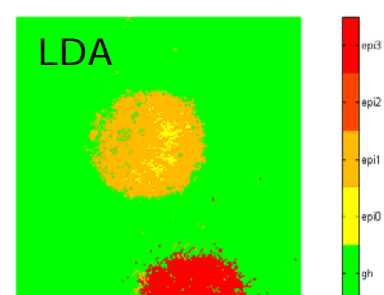
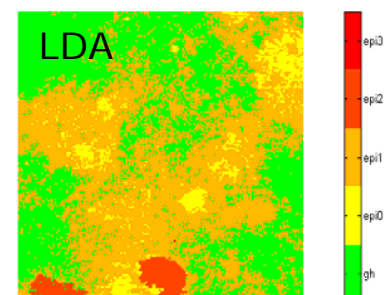
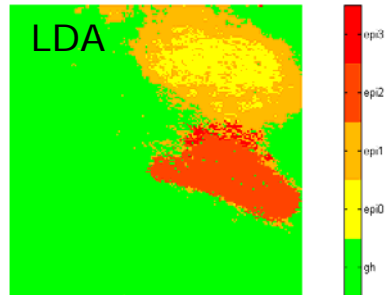
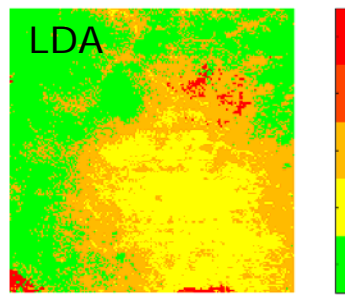
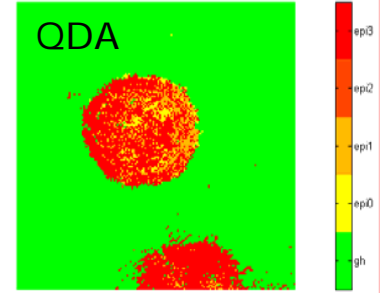
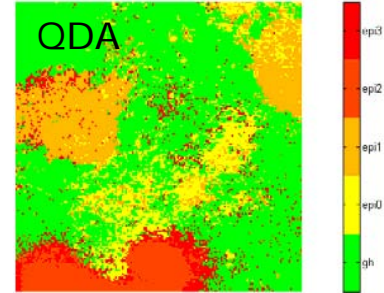
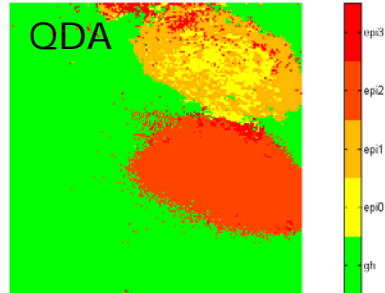
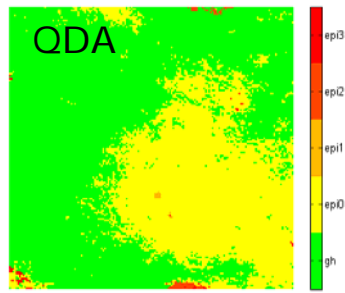
Grade 1

Grade 2



Grade 3

Grade 3





- **Method for classification of allergy tests (patch test)**
  - In-vivo and non-invasive method
  - Visible Light (380-780nm)
  - Spectral Imaging Technology
  - Hyperspectral classification with > 80% accuracy (pixel-basis)
  
- **Advantages**
  - Objective result obtained from chemometrical features
  - Reduction of diagnosis effort (for the physician)
  - Physician can concentrate on relevant results
  
- **Future work**
  - Extension of training data (number of cases, variations)
  - Evaluation for prick test
  - Other classifiers (SVM, wavelet-based features, ICA, etc.)
  - Spatial connectivity (contextual classifiers, etc.)



**Thank you for your attention!**