Mathematical analysis of satellite images

Part 1

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1. Introduction: the evolution of remote sensing
**Needs?**
- The exhausting of local and global resources (first: oil)
- Global problems
- The extinction of species
- Club of Rome
Therefore natural resources should be managed, based on exact survey!

**Opportunities?**
- Space technology
- Sensors
- High speed data transfer
- 1972: launch of the first LANDSAT (ERTS) satellite
- Fast computers with graphical capabilities
- Digital image processing
Remote sensing:
from data acquisition to thematic evaluation

The 3 main components of remote sensing system
The parts of optical wavelength interval
The first series of Landsat satellites (1, 2, 3) (1972-1983)
SPOT 5 HRG sensor
Very high resolution satellite images
(0.5 m x 0.5 m – 4 m x 4 m-es ground resolution)

IKONOS satellite image
A part of IKONOS multispectral satellite image (4 m)
Sapporo, Japan, 1999 October 6
Space Imaging

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The first Hungarian satellite: MASAT-1
http://cubesat.bme.hu
2012 February 13 – 2015 January 9

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Long-term European programme: Copernicus …and Sentinel satellites

Sentinel-1A (2014. 04. 03.): weather independent, radar sensor
Sentinel-2A (2015. 06. 23.): high resolution multispectral optical sensor
2. Raw material: data acquisition and pre-processing
The physical background of remote sensing

• Passive, reflective systems:
  - Sun is the source of electromagnetic (EM) radiation
  - Sampling “windows” of the whole EM spectrum

  ▪ Different land covers reflect differently:
    - crops, - water, - soil

  ▪ Sensors measure the intensity of electromagnetic radiation arriving from the Earth’s surface
Spectral response curves
What are the acquisition bands used for?
The diversity of remote sensing

**Satellites:**
- Geostationary orbit: 36 000 km
- (Near) polar orbit: 450-1000 km

**Airplanes:**
- 300 m-10 km

**Drones:**
- UAV - Unmanned Aerial Vehicle or RPAS - Remotely Piloted Aircraft Systems:
  - 30-600 m

**Gliders:**
- 100-300 m

**Terrestrial observation:**
- 5 m

- Carrier
- Height
- Time
- Sensors
- Wavelength

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Scanning acquisition:
What does a remote sensing image contain?

Pixels --- elementary pieces of surface

Band values within a pixel
The main parameters of remote sensing systems

Spatial:
- Spatial coverage
- Ground resolution

Spectral:
- Spectral resolution
- Radiometric resolution

Temporal:
- Temporal resolution (cycle length)

- Other factors: data access (availability, speed, price)
The mosaicking of image tiles

<table>
<thead>
<tr>
<th>Scene ID</th>
<th>Date</th>
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<tbody>
<tr>
<td>1333</td>
<td>2012.08.06.</td>
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<tr>
<td>8364</td>
<td>2012.08.18.</td>
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<td>8481</td>
<td>2012.08.18.</td>
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<td>4565</td>
<td>2012.08.25.</td>
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It is clear that an accurate Digital Elevation Model is inevitable.
Two complete coverages of VHR images (Pléiades)

Pléiades, 2013.05.18. + Pléiades, 2013.07.17.
Pixel-based fusion („merge”)

- Principal Component Analysis (PCA)
- Modified Intensity-Hue-Saturation Merge (MIHS)
- In-house developed fusion, based on high pass filter (HPF)
3. Evaluation: only visual approach?
The thematic evaluation of remote sensing images

2003. 03. 29., Landsat 7 ETM+

A part of a crop map

2003. 07. 27., Landsat 5 TM

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The diversity of thematic categories

- Aszályal erősen sújtott
- Aszályal közepesen sújtott
- Aszály által érintett
- Aszály által nem érintett
- Aszály által nem veszélyeztetett

- Öszi búza
- Tavaszi árpa
- Öszi árpa
- Kukorica
- Silókukorica
- Napraforgó
- Cukorrépa
- Lucerna
- Vízfelszínek
- Nem mezőgazdasági területek
- Egyéb szántóföldi növények

- 1.1 Lakott területek
- 1.2 Ipari, kereskedelmi területek
- 1.3 Bányák, lerakóhelyek, építési munkahelyek
- 1.4 Mesterséges, nem-mezőgazdasági zöldterületek
- 2.1 Szántóföldek
- 2.2 Állandó növényi kultúrák
- 2.3 Legelők
- 2.4 Vegyes mezőgazdasági területek
- 3.1 Erdők
- 3.2 Cserjes és/vagy lágyszárú növényzet
- 3.3 Növényzet nélküli, vagy kevés növényzettel fedett nyílt területek
- 4.1 Szárazföldi vízenyős területek
- 5.1 Kontinentális vizek

- Valószínűsített szőlő-ültetvény
- Valószínűsített gyümölcsös-ültetvény
- Valószínűsített szőlő-gyümölcsös-ültetvény
- Aprotáblás művelési szerkezet
- Bizonytalan, de lehetséges ültetvény

- Erdő területek károsodása
- Nincs károsodás
- Kis mértékű károsodás
- Közepes mértékű károsodás
- Érős károsodás
- Egyéb terület

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Texture: the regular changes of intensity values
The two basic methods of remote sensing data evaluation: visual interpretation and digital image processing

<table>
<thead>
<tr>
<th>Feladat</th>
<th>Vizuális interpretáció (szem + agy rendszer)</th>
<th>Számítógépes kiértékelő rendszer</th>
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<tbody>
<tr>
<td>Geometriai összefüggések, struktúrák felismerése</td>
<td>kitűnő</td>
<td>gyenge</td>
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<td>Textúra felismerése, azonosítása</td>
<td>jó</td>
<td>gyenge</td>
</tr>
<tr>
<td>Textúra mérése</td>
<td>gyenge</td>
<td>kitűnő</td>
</tr>
<tr>
<td>Tónusok elkülönítése</td>
<td>közepes</td>
<td>kitűnő</td>
</tr>
<tr>
<td>Megbízhatóság, objektivitás, reprodukálhatóság</td>
<td>közepes</td>
<td>jó</td>
</tr>
<tr>
<td>Feldolgozási sebesség</td>
<td>gyenge</td>
<td>kitűnő</td>
</tr>
<tr>
<td>Bonyolult szakértelem, egyéb ismeretek alkalmazása</td>
<td>jó</td>
<td>közepes</td>
</tr>
<tr>
<td>Több adatforrás vagy időpont együttes kiértékelése</td>
<td>gyenge</td>
<td>kitűnő</td>
</tr>
</tbody>
</table>
3.1. Numerical evaluation
The basic task of image processing and the elementary solutions of classification

Pixels belonging to categories

The intensity vectors of categories show a typical probability distribution in certain parts of intensity space.
Clusters and thematic categories
3.2. Visual evaluation
Application in remote sensing subsidy control (CwRS)

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ikonos</td>
<td>2013.06.21.</td>
</tr>
<tr>
<td>Ikonos</td>
<td>2013.07.02.</td>
</tr>
<tr>
<td>GeoEye</td>
<td>2013.07.03.</td>
</tr>
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<td>GeoEye</td>
<td>2013.07.06.</td>
</tr>
</tbody>
</table>

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CwRS, Example#1: tree density counting

Ikonos, 2012.07.02.

Pléiades, 2012.08.18.

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CwRS, Example#2: the detection of sunflower

CwRS, Example#3: cereal stubble (weed-free)

3.3. Combined solutions
The detection of weed-infected areas

Weed infection in soybean parcels, detected with the quantitative evaluation of NDVI map. The grades of weed infection can be observed with Pleiades images on soybean stubble. The extent of infection can be well measured within parcels.
Automatic delineation of forest areas

Object-based Image Analysis (OBIA)
The quantitative comparison of Pleiades images

2012.08.06. → 2012.08.18.: Left to right: difference, 2012.08.06, 2012.08.18.
4. Practical applications
4.1. The National Operational Crop Monitoring and Production Forecast Programme (CROPMON)
Data Flow in CROPMON

- **Precalibration, historical data**
- **Crop maps and area figures**
- **Reference data**
- **High resolution satellite data**
- **Low resolution satellite data**

CROPMON INFORMATION EXTRACTION SYSTEM

- **Development assessment**
- **Yield forecast**
- **Production Reports**
- **Drought Alert Reports**
- **Mathematical analysis of satellite images**

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The FÖMI RSC crop yield forecast model

- **Basics:**
  - combination of spatial with spectral/temporal information (high res. + AVHRR)
  - NOAA AVHRR images and crop maps => crop specific temporal profiles

- **Features:**
  - generic: works for several crops
  - year independent
  - area independent
  - reliable, accurate, timely
Area measurement: Crop maps – detailed analysis at pixel level

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4.2. Waterlog and flood monitoring
Monitoring the impact of waterlog using satellite image time series

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Waterlog maps derived from IRS WIFS medium resolution satellite data

- good overview at country and at county level
- frequent (3-4 days), good for change detection
- cover the whole country with low cost
- quick processing
Monitoring the change of waterlog

The dynamics of waterlog and its impact can be quantified. The affected areas can be assessed by villages as well.
Real-time flood monitoring, 2001

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4.3. The building up and maintenance of Land Parcel Identification System (LPIS; MePAR in Hungarian)
Review and change management of physical blocks

Example #1

The reduction of eligible area because of road construction

Orthophoto 2007, MePAR 2010

Orthophoto 2011, MePAR 2012

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Review and change management of physical blocks

Example #2

The reduction of eligible area because of urban development

Orthophoto 2007, MePAR 2010

Orthophoto 2011, MePAR 2012
Review and change management of physical blocks

Example #3

The reduction of eligible area because of the extension of industrial area (opencast)
The MePAR land cover system
4.4. Control with Remote Sensing of Agricultural Subsidies
Remote sensing control of area-based agricultural subsidies

The comparison of claims and real situation:

- **Cultivated crop**
- **Parcel area**
- **Good Agricultural and Environmental Conditions (GAEC)**


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Basic data of CwRS:
high and very high resolution satellite images (HR, VHR)

CwRS central database

Satellite images

VHR

SPOT 2 XS
SPOT 4/5/6/7 Xi
Landsat 5/7/8 (E)TM
IRS-1C/D/P6/R2 LISS
RapidEye

High resolution
(10-25m) time series

Very high resolution
(0.5-1m)

Ikonos
QuickBird
Pléiades 1A/1B
GeoEye
WorldView 1/2/3

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Computer-aided Photo-interpretation (CAPI) with GIS software developed within FÖMI

Digitised parcel drawing

Claim database

Very high resolution (VHR) satellite images for area measurement

High resolution satellite image time series for crop determination

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Different crop types can be distinguished at parcel level using Very High Resolution images.
Control of minimum cultivation practice

The protection of permanent grassland: at least one mowing per year or regular grazing
Control of minimum cultivation practice

Encroachment of unwanted weeds must be prevented
GAEC - the checking of prevention of soil erosion with DEM+GIS
(DEM→steep parcels, CAPI→parcels with row crops, intersection: problem!)
5. Education and university collaboration
Collaboration in research and education between ELTE and FÖMI

- 1983-84: Joint development of a system evaluating satellite images
- 1985-2002: Occasional collaborations, joint publications
- 1999, 2005: Segment-based classification appears in PhD projects
- 2003: The establishment of Faculty of Informatics. Further joint research projects start
- 2004: The launching of Geospatial Information Systems educational module. It contains the subject Analysis of Remote Sensing Images (2+2), maintained jointly by ELTE and FÖMI
- 2006-2011: Twelve students attended at cooperative education in FÖMI
Education: the course „Analysis of Remote Sensing Images”

- Started in 2005, 5th year MSc students. The curriculum contains a series of about 400 slides within 15 lectures.

- Presentation (I. László, FÖMI) includes the theoretical background of remote sensing (pre-processing, image analysis, statistical classification) and covers wide variety of practical applications.

- Lab seminars (R. Giachetta, ELTE): students implement programming tasks in connection with remote sensing (transformations, filtering, segmentation, clustering, classification).
Innovative benefits of collaboration

- Main contact point: Department of Algorithms and Applications, István Fekete assoc. prof.

- Joint research, development and educational results

- Students gain insight into current operational applications

- Introduction of new scientific results into projects

- Students may get a professional practice at FÖMI

- Rising generation of highly educated colleagues
Thank you for your attention!