Object-oriented image analysis methods in disaster risk management – state-of-the-art and prospects for the Philippines

Dr. Norman Kerle. ESA Department
ITC-OOA-Group
ERDT Visiting Professor
back in the Philippines

- Masters thesis research at PHIVOLCS

Research motivation in 1996

Annual number of natural disasters in the Philippines

- # disasters per year
- 10 per. Mov. Avg. (# disasters per year)

7 disaster events
...back in the Philippines

Paradise unleashed: Tourist vulnerability to natural hazards in the Philippines, and economic consequences of tourism decline following a natural disaster [Englisch] [Taschenbuch]

Norman Kerle (Autor)
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...back in the Philippines

Annual number of natural disasters in the Philippines

Source: CRED, 2014
...back in the Philippines

Taught courses with GIZ and UPVTC on disaster risk management (2009 and 2010)
...back in the Philippines

United Nations Joint Board on GIS paper with Olaf Neussner, GIZ

Local Flood Early Warning Based on Low-Tech Geoinformatics Approaches and Community Involvement: A Solution for Rural Areas in the Philippines

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Introduction and background

The vast majority of the more than 200 activations of the International Charter: Space and Major Disasters to date (International Charter, 2009), including the very first event in 2001, have been in response to flood disasters. Such events come in various forms, at times related to excessive precipitation due to tropical storms, at others caused by snow melt, coastal or river dam breaks, volcano crater rim collapses or subglacial outbursts. With disasters defined as hazardous events causing damage that exceeds the coping capacity of the affected community, the spatial scale of such events is highly variable, depending largely on the distribution and accumulation of assets in threatened areas. Such accumulations are becoming increasingly common, reflecting both global population growth (and the consequent movement of frequently marginalized people into such areas), but also an increase in overall asset wealth that may be adversely affected (Grim et al., 2008).
Lecture outline

(1) Me @ ITC

(2) Principles of OOA & use for DRM

(3) Recent research

(4) Prospects for Philippines & Outlook
My background

- ITC/University of Twente (Enschede, The Netherlands)
- PhD in geography/ Volcano remote sensing (Uni Cambridge)
- Geoinformatics for disaster risk management (hazard/risk/vulnerability/damage)
- Currently ERDT Visiting Professor

- Training & capacity building
- Knowledge development and research collaboration
- Advisory services

www.unu-drm.nl
Object-oriented analysis for disaster risk management

Disaster Risk Management (DRM)  |  Object-oriented Analysis (OOA)

Disaster risk
- Different concepts
- Expected losses ($f[hazard, period]$)

- **Risk** = **Hazard** * **Vulnerability**$^\text{EaR}$ * **Amount**
  
  ($R=H*V*A$)

- EaR (elements at risk): not only physical
- $H$: $f$[type, magnitude]
- $V$: physical, social, economic, environmental, etc. (0→1)
- Amount: quantifiable?
- Note: all elements of risk are spatial

(2) Principles of OOA & use for DRM
Basics of object-oriented analysis

DRM | OOA

OOA
- OOA is a form of image classification
- Objects derived from segments (segmentation-based analysis, OBIA, GEOBIA)
  - 1. step: segmentation: old concept (~1970s) – partition an image into homogenous units (ideally creation of meaningful objects)
  - 2. step: classification of those units
Basics of object-oriented analysis

DRM | OOA

OOA
- Segmentation also at multiple scales, and using auxiliary information
- Note: we do most OOA work in eCognition software

Any type of raster image, and thematic GIS layer

Super-objects
Classification level
Sub-objects
Pixel
Basics of object-oriented analysis

DRM | OOA

OOA

- Main difference over pixel-based methods: objects have extra features (spectral, geometric, contextual) = useful for classification
- Allows use of feature and process knowledge
Basics of object-oriented analysis

- Pixel-based: landcover (spectral information); OOA - landuse

- **Challenge**: we need detailed feature and process knowledge
Hazards have many faces – our data and approaches need to reflect that.
Question: do we always understand the hazard, its spatio-temporal characteristics, and its effects?

Example: volcanic hazard

Better: volcano-based hazards

All sub-hazards have their own characteristics

Many specific hazards exist
OOA for DRM

- Our group addresses
  - use of OOA for different hazards and risk elements
  - different aspects of risk
  - methodological work (better segmentation, feature and threshold selection)

Remote sensing for DRM

Domain focus

- Hazard
- Vulnerability
- EaR
- Risk
- Damage
- (Recovery)

Technical focus

- Landslides/erosion
- Social
- Urban/infrastructure

OOA (in eCognition)

(3) Recent research

- Refugees camps; metrics for recovery
- Pictometry-/UAV-based damage

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OOA for DRM

- Focus on **landslide** work – find solutions to this type of mapping problem
**Hazard: Landslide work**

- Work with several PhD students and postdocs
- work of Tapas Martha
  - conceptualization of a landslide
  - segmentation based on satellite data and elevation data
  - removal of false positives
  - classification of different landslide types

**OOA-based landslide mapping**
Martha et al., 2010 (Geomorphology)
Hazard: Landslide work

- Problem: trial & error work
- What segmentation parameters?
- One-fits-all?
- Work on statistical optimization of segmentation
- Plateau objective function (POF) to select appropriate scale factors

Hazard: Landslide work

- Ping Lu (Uni Florence): OOA-based landslide change detection
- Also focused on multi-scale segmentation optimization

Problem: change detection

OOA-based landslide mapping
Martha et al., 2010
(Geomorphology)

Objective segmentation
(POF)
Martha et al., 2011
(IEEE TGRS)

Change detection
Lu et al., 2011
(IEEE GSRL)

Pre-event image
Post-event image
Landslide map
Hazard: Landslide work

- Andre Stumpf: classification parameter and threshold selection
- How to choose from hundreds of object features and the best threshold?
- Random Forest method (data mining/active learning based on samples)
Hazard: Landslide work

- Tested on air- and spaceborne data of 4 different sites
- Accuracies of 73-87%

Objective segmentation (POF)
Martha et al., 2011 (IEEE TGRS)

Change detection
Lu et al., 2011 (IEEE GSRL)

Objective parameter selection
Stumpf & Kerle, 2011 (Remote Sensing of Environment)
Hazard: Landslide work

- Tapas Martha: OOA-based landslide detection based only on pan-chromatic data
- Again use of POF
- Focus on texture measures
- Time-series analysis

Problem: limits of pan-chromatic data
Hazard: Landslide work

Objective segmentation (POF)  
Martha et al., 2011  
(IEEE TGRS)

Change detection  
Lu et al., 2011  
(IEEE GSRL)

Objective parameter selection  
Stumpf & Kerle, 2011  
(RSE)

Use of panchromatic data  
Martha et al., 2012  
(ISPRS)

UP Diliman - OOA for DRM - 2014
Hazard: Landslide work with LiDAR data

- So far all work focused on optical data
- **Miet Van Den Eeckhaut**: detection of forested landslides in single-pule LiDAR data
- No use of additional optical data
- Area in Flanders, Belgium; > 200 old deep-seated and shallow slides
- Almost impossible to detect in optical data

(Elevation exaggeration x1; @Google Earth)
Hazard: Landslide work with LiDAR data

- Procedure:
  - Creation of LiDAR derivatives
  - Multiple segmentation based on POF
  - Detection of main scarp
  - Downslope growing using evidence from side and base scarp, as well as interior
  - Good detection of deep slides (71% of main scarps, >50% of associated landslide body
Hazard: Landslide work with LiDAR data

Expert

Automatic
Hazard: Landslide work with LiDAR data

- Promising results given the challenging terrain

OOA and LiDAR
Van Den Eeckhaut et al., 2012 (Geomorphology)

Relevant for the Philippines
Other risk aspects – Damage mapping

- More recent work
- Image-based damage mapping *per se* is very difficult
- Very little (and not very convincing) OOA work

(Pham et al., 2014)
Other risk aspects – Damage mapping

- With Markus Gerke: use of oblique image data from Pictometry
- 5 perspectives, in principle allowing comprehensive damage evaluation
- Example from Haiti (2010)
Other risk aspects – Damage mapping

- Many features were calculated from the data (digital elevation model, texture, etc.)
Damage mapping results:

Western view example

- Photogrammetric processing
- Focus on planarity
- Machine learning classification

Damage mapping with Pictometry data
Gerke & Kerle, 2011 (PE&RS)
Damage detection with point clouds
METHODOLOGY

Building level

Point cloud → Segmentation

UAV images

Collapsed (D5) → Roof

Non-collapsed (D1-D4) → Standing

Roof → Rubble piles

Facade → No rubble piles

Building's surroundings

Colors indicate orientation

Facade's geometry

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DAMAGE DETECTION WITH POINT CLOUDS

A. 2m

B. 3m

Partial roof collapse

C. Rubble piles

D. 2m

RUBBLE PILES

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Damage mapping with UAV data
Fernandez Galarreta et al., in review
METHODOLOGY

Point cloud
UAV images

Building level
- Segmentation
- Collapsed (D5)
- Non-collapsed (D1-D4)
- Roof
- Facade
  - Standing
  - Rubble piles
  - No rubble piles
- Building's surroundings
  - Facade's geometry
  - Inclined
  - Non-inclined

View/facade level
- OOA
- Extracted features:
  - 3D construct visualization
  - Random scenarios
  - Expert analysis
  - Facade assessment
  - Per-view score D1-D2-D3-D4
  - Per-building decision tree
  - Uncertainty evaluation

D5
D4
D3
D2
D1

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DAMAGE DETECTION WITH OOA
EXPERT-BASED ASSESSMENT

- Provide extra information for visual damage assessment
Outlook & trends

Status quo:

- OOA has proven a versatile and useful image analysis concept
- It allows effective use of process and feature knowledge
- Good progress in automating methods

- High dependence on eCognition (>50% of all papers; high cost)
- Still limited transferability of solutions (and use of non-expert community)
Outlook & trends

Research needs:

- Segmentation scale, feature and threshold selection remain difficult
- Actual multi-scale analysis is still rare
- Feature behavior across scales poses challenge
- Work on better image metrics
- Better use of machine learning techniques
Outlook & trends – 3D data processing

- 3D data are becoming increasingly available (LiDAR point clouds, geophysical data)
- Many inspiring developments from biomedical field. Example: > 500 CT slices of a mouse

  ![CT images of a mouse](image)

- eCognition result:
Outlook & trends – 3D data processing

- Islam Fadel: OOA-processing of geophysical data (seismic/tomographic/gravity data)

OOA of 3D geophysical data I
Fadel et al., 2014 (Geophysical Journal International)

OOA of 3D geophysical data II
Fadel et al., 2013 (JAG)
Significance & imitations for the Philippines

- Advanced image analysis (including OOA/OBIA) for different risk aspects and hazards
- Some approaches (rulesets) can be adapted to the needs of Philippines
- Unique problems, unique solutions
  - Institutional and technical capacity (DOST, PAGASA, UP, etc.)
  - DREAM-LiDAR
  - Own satellite
Significance & imitations for the Philippines

- DREAM-LiDAR
  - One of the 8 components of DOST Project NOAH
  - Essentially finished
  - 15-20 cm vertical accuracy (relative accuracy of Dutch national LiDAR data (AHN-2) is 4 cm)
  - Data available to all (!)
  - Most of the landmass, 200 watersheds/basins

(4) Prospects for Philippines & Outlook
Significance & imitations for the Philippines

- DIWATA (micro-satellite)
- To be launched in 2016
- No further specifications known yet
- **Caution**: globally a move towards constellations/networks (of physical infrastructure and organizational) (DMC, Pleiades, Sentinel Asia)
  - One satellite alone will not solve problems (data availability is less and less the problem)
  - Being part of a concerted regional or global effort is advisable (access to multi-type data, better temporal resolution)
Summary

- Challenging hazard exposure situation in the Philippines
- Challenging risk assessment and mitigation situation (logistical, political, sociological, economic)
- On the other hand heavy investment in technical, organizational and research capacity
- Disaster risk has been singled out as a major threat, and it being seriously addressed
- Good international links (USGS, Japan, ITC) have been helping to improve capacity
- More effort would be useful to adopt existing solutions, including in geoinformatics
Questions?

- Our OOA work continues – check www.itc.nl/ooa-group for updates
- Same for full references
- Papers also on
  https://www.researchgate.net/profile/Norman_Kerle
- Or email: n.kerle@utwente.nl

Thank you
Other risk aspects – Elements at risk

- Janak Joshi: Problem - building extraction from optical satellite data
- Chicken & egg: we’d like to have a DEM/DSM, but photogrammetry is imperfect

Solution:
- Create an (imperfect) DEM/DSM
- Use in OOA (distinguish buildings from similar looking low features)
- Use the extracted buildings to correct the DEM/DSM
Other risk aspects – Elements at risk

- Geoeye image
- Initial DSM
- OOA-derived buildings
- Evident errors
- Assignment of height
- Corrected DSM
Other risk aspects – Elements at risk

- Improved DSM, useful for example for flood modeling
Annemarie Ebert: Social vulnerability (SV): “people’s differential incapacity to deal with hazards, based on the position of the groups and individuals within both the physical and social worlds” (Clark et al., 1998)

Traditionally assessed using census data (that often don’t exist)

Solution: use physical proxies

We selected 47 variables

In stepwise multiple regression against census-based SV index found 8 variables that explained 60% of the variance
Other risk aspects – Social vulnerability

SV mapping with OOA
Ebert et al., 2009 (Natural Hazards)
Other risk aspects – Deprivation

- We use similar approaches to map deprivation (e.g. slums)
- **Divyani Kohli**: use of spatial metrics to describe urban units extracted with OOA
- **Ontology** used to formalize (local/specific) knowledge of slums
- Currently being used to parameterize OOA-based slum detection

**Ontology-based slum detection**
Kohli et al., 2012 (CEUS)

**OOA-based slum detection**
Kohli et al., 2013 (Remote Sensing)
Other risk aspects – Deprivation

- Access Network → Connected / not connected with neighboring areas
  - has
  - Structure → Regular / Irregular
    - is of
    - Width → Road → has Type
      - is
      - Paved/Un-paved
        - Type is Access, local, district or arterial street
        - Paved/Un-paved is Material (mud, gravel, cement)
        - Width is Specific value or range

- Shape
  - Settlement → Density
    - High or very high

- Level
  - Level 40 [shape=0.5 compact=0.5] creating ‘Level’
  - unclassified with NDVI > 0.1 at Level: veg
  - unclassified with Mean Layer 2 ≤ 131 at Level: sl

- Built
  - unclassified with GLCM Entropy (quick8\11) Layer:
  - Slums
    - built with GLCM Contrast (quick8\11) Layer 3 (β)
    - Slums at Level: merge region
  - Slums with Area < 5185 Pol at Level: built
  - Slums with Asymmetry > 0.77 at Level: built
Hazard: Erosion detection

- Shruthi Rajesh: use of high-resolution satellite data to map gully erosion
- Similar approaches to what we developed for landslides (directional texture, etc.)
- Removal of false positives was challenging
Hazard: Erosion detection

Problem: linear element detection

Gully erosion detection
Shruthi et al., 2011
(Geomorphology)
Hazard: Erosion detection

- Change detection for gully systems (2001-2009)

Problem: change detection of lines
Hazard: Erosion detection

- Use of medium-resolution data (ASTER), with training based on high-resolution GeoEye-1, also using RandomForests

Gully system detection in medium-resolution imagery
Shruthi et al., 2014 (Geomorphology)