Remote Sensing for Environment of Angkor Site (REAS)

Cheng Wang
wangcheng@radi.ac.cn

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Outline

- Background
- REAS Project
- Current Progress
Research Background:

Brief Review

Kulun Mountain

Angkor Wat
Restoration and Protection of Angkor Site

– A national priority of Cambodia supported by UNESCO and over 20 its member countries.
– The Tokyo Declaration (Oct. 13, 1993) – Intergovernmental Conference on Safeguarding and Developing Angkor

➢ Restoration of Preah Khan Temple and Phnom Bakheng by USA
➢ Restoration of the Terrace of Elephants by France
➢ Restoration of Ta Keo by the Chinese government
Remote Sensing Applications on Angkor Site

- 1992, University of Arkansas (USA), Landsat TM, investigated AOI
- 1994, NASA Jet Propulsion Laboratory, Radar, revealed drainage network
- 2006, University of Florida, Landsat TM/ETM, land cover change monitoring
- 2010, Keio University (Japan), Landsat TM and SPOT-PAN, mapped geomorphology
**Airborne LiDAR Application on Angkor**

Airborne LiDAR was carried out in 2012 by a group organized by University of Sydney. The experts explored the earlier and secret Angkor ancient city hidden in the forest and Paddy for hundreds of years.

**Shaded relief map of terrain**
- **Green:** previously-documented archaeological features
- **Red:** newly-documented features indicative of an extensive urban layout.

**Oblique view of Angkor Wat**
- **Top:** digital orthophoto with elevation derived from the lidar DSM
- **Bottom:** DEM derived from the LiDAR
Challenges:

- Environmental deterioration in Angkor and neighboring areas
- Existing projects have focused on heritage restoration and protection, lacking of a systematic approach to solve the problems
- Geospatial technologies can provide a systematic approach for studying the complex natural environment and human-environment interactions in Angkor (400 km²) and surrounding areas (5,000 km²)
Prof. Huodong Guo of HIST and RADI and Director BUN Narith of APSARA signed an MOU during the 37th session of the UNESCO World Heritage Committee in Phnom Penh, June 2013

Cambodian Deputy Prime Minister H. E. Dr. Sok An met with the HIST/RADI delegation, and expressed full support for the proposed collaborative project.
June 2013, Siem Reap
Determine research contents

- Forest dynamics monitoring
- Water system reconstruction
- Ground subsidence monitoring
- 3D reconstruction and visualization
Objectives:

- monitoring Angkor site and its surrounding environment
- better understanding the relationship between them

- Forest ecosystem (deforestation/fire)
- Water system (flood/soil erosion)
- Ground subsidence (loosen/displacement)

Angkor Site and its environment

- Climate system (wind/temperature/precipitation)
- Soils
- Rock Types
- Human Activity (tourism/urbanization)

Spatial database of Angkor Site
3D simulation and GIS
Policy recommendations for heritage protection and sustainable development
Training of heritage management personnel

Multi-platform remote sensing data
Basic geodata
Auxiliary data

Optical image
Radar data
LiDAR data
Satellite platform
Ground collection
Space technologies provide a systematic approach for studying the complex natural environment and human-environment interactions in Angkor (400 km²) and surrounding areas (5,000 km²).
Part 1: Forest dynamics monitoring

Part 2: Water system monitoring

Part 3: Ground subsidence monitoring

Part 4: 3D reconstruction and visualization

Part 5: Spatial database of Angkor Site

Part 6: Capacity building
<table>
<thead>
<tr>
<th>Satellite/Sensor</th>
<th>Acquired date</th>
<th>Acquired date</th>
<th>Acquired date</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 Landsat-TM imageries (30m)</td>
<td>1985-3-23</td>
<td>1996-01-02</td>
<td>2006-2-9</td>
</tr>
<tr>
<td></td>
<td>1989-01-22</td>
<td>1996-6-29</td>
<td>2006-12-15</td>
</tr>
<tr>
<td></td>
<td>1990-11-17</td>
<td>2000-03-25</td>
<td>2009-01-05</td>
</tr>
<tr>
<td></td>
<td>1991-1-3</td>
<td>2000-8-5</td>
<td>2009-2-1</td>
</tr>
<tr>
<td></td>
<td>1994-01-28</td>
<td>2002-01-10</td>
<td>2013-1-8</td>
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<tr>
<td>SPOT-5</td>
<td>2013-1-21; 2013-1-16;</td>
<td>2012-12-26; 2.5m</td>
<td></td>
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<tr>
<td>Quickbird</td>
<td>2004-1-6; 2004-4-24; 0.6m</td>
<td></td>
<td></td>
</tr>
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<td>ALOS-SAR; Radarsat-SAR</td>
<td>1996-2013, 30m, 3m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTER-DEM</td>
<td>2009-V1 product; 30m</td>
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</tr>
</tbody>
</table>

Resolution 30 m — 0.6 m
REAS Project: Field Work

Oct. 2013, laser scanning and LUCC validation
Accuracy Assessment

- sixteen field samples were validated in Nov. 2013
- only two samples (red dot) were misclassified

Oct. 2013, laser scanning and LUCC validation
Land use/land cover change mapping over 5000 km² area
Forest area change analysis during the past 30 years
Urban area change analysis during the past 30 years
Ancient water system reconstruction
Monitoring land subsidence from 2011-2013
Spatial database designing for Angkor Site
Capacity building
Research Progress: Land Cover Change

Data source (1985-2014)
- Landsat MSS
- Landsat TM
- HJ-1A
- Landsat LOI

Classification Map (2009/01/05)

- Urban area: gradually increasing
- Forest area: unstable decreasing
- Water area: seasonal fluctuations
sixteen field samples were validated in Nov. 2013
only two samples (red dot) were misclassified
REAS Project Progress: Forest Change
Reas Project Progress: Forest Change

Forest changes during three periods (1989-2000-2014)

- Deforested area is 575 km² from 1989 to 2014, which occupied almost 35% of the total area.
- Reproduction area is 62 km² from 1989 to 2014, which is about 5% of the total area.
- 22% deforested area during the period of 2000-2014, while only 13% during the period of 1989-2000.
- As time goes, deforestation spread from south to the north of Kulen mountain.

Note: Kulen Mountain was defined in our study as the area with 40 m a.s.l.
REAS Project Progress: Forest Change
**RS Data:** ZY3 image (2 m), Jan. 5, 2014

**Image Classifier:** Object-Based Classifier

**Features used:** Ndvi, Area, Home, Color, Smoothness, Compactness, Shape index, Rectangular fit

**Study Area:** Kunlen Mountain area from 40-120 m above seal level.

- Forest areas of Kunlen Mountain mainly located above 40 m a.s.l.
- Frequent human activities are the main reason which led to forest changes during the past 30 years.
Research Progress: Economic Forest Extraction

Classified objects

- Total Number: 345
- Min. Area: 0.000534 Km²
- Max. Area: 0.342613 Km²
- Sum Area: 5.837428 Km²
- Area<0.03 km²: 298 (86.3%)
- Road 67 buffer: 4 Km
- Count: 208 (60.29%)
- Area: 2.09 Km² (50%)
Research Progress: Economic Forest Extraction

(F-N-F) : economic forest
Urban area:

- Before 2000, increased slowly (5.9%)
- 2000-2006, increased very fast, especially from 2002 to 2006 (48.8%)
- 2006-2013, increased slowing
- 15.5% from 1989-2013

Expansion direction along the Siem Reap River (N-S) and the road (W-E)
REAS Project Progress: Urban Change
### Urban area change during 2004-2012 in Siem Reap (km²)

<table>
<thead>
<tr>
<th>Year</th>
<th>Urban</th>
<th>Crop &amp; Grass</th>
<th>Forest</th>
<th>Water</th>
<th>Vacant</th>
<th>Road</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>2004</td>
<td>7.18</td>
<td>13.13</td>
<td>8.36</td>
<td>0.16</td>
<td>0.39</td>
<td>1.79</td>
<td>31.00</td>
</tr>
<tr>
<td>2012</td>
<td>10.79</td>
<td>10.89</td>
<td>7.34</td>
<td>0.32</td>
<td>0.25</td>
<td>2.35</td>
<td>31.94</td>
</tr>
</tbody>
</table>
Small changes, depends on the acquisition time of the used image

The changes are mainly distributed around Tonle Sap Lake and Angkor Wat
The flood of 2000

Flood water covered 73% area of crop field and 37.7% area of forest

<table>
<thead>
<tr>
<th></th>
<th>20000325</th>
<th>20001104</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>Percentage (%)</td>
<td>Area (km²)</td>
</tr>
<tr>
<td>Water</td>
<td>558.48</td>
<td>1205.87</td>
</tr>
<tr>
<td>Crop</td>
<td>2181.00</td>
<td>365.91</td>
</tr>
<tr>
<td>Urban</td>
<td>0.62</td>
<td>0.43</td>
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<tr>
<td>Barren</td>
<td>136.73</td>
<td>411.09</td>
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<tr>
<td>Grass</td>
<td>881.53</td>
<td>840.96</td>
</tr>
<tr>
<td>Forest</td>
<td>2534.81</td>
<td>1353.01</td>
</tr>
<tr>
<td>Wetland</td>
<td>572.09</td>
<td>2685.27</td>
</tr>
</tbody>
</table>

(Top: TM images; Bottom: classification maps)
REAS Project Progress: Water Change
洞里萨湖面积可由旱季的2500km²增长到雨季的15000km²。
GLAS provided global measurements of the Earth’s land surface topography, which was aboard the NASA Ice, Cloud, and land Elevation (ICESat) satellite.

Technical characteristics:
- **Status**: launched Jan. 2003
- **Platform**: space-borne
- **Wavelength**:
  - 1064 nm (vegetation)
  - 532 nm (atmosphere)
- **Pulse frequency**: 40 Hz
- **Pulse width**: 5 ns
- **Pulse form**: Gaussian
- **Footprint diameter**: 60-70 m
- **Transmit energy**: 5 mJ
- **Along-track separation**: 170 m
- **Cross-track max**: 15 km
- **Cross-track min**: 2.5 km
- **Repeat cycle**: 183 days
- **Life-time**: 3 years

http://icesat.gsfc.nasa.gov
<table>
<thead>
<tr>
<th>时间</th>
<th>GLAS点数(个)</th>
<th>均值 (m)</th>
<th>标准差</th>
<th>最小值 (m)</th>
<th>最大值 (m)</th>
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<tbody>
<tr>
<td>2004年 2月</td>
<td>144</td>
<td>-13.894</td>
<td>1.279191</td>
<td>-17.985</td>
<td>-10.044</td>
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<tr>
<td>5月</td>
<td>92</td>
<td>-16.096</td>
<td>3.046617</td>
<td>-18.699</td>
<td>-10.733</td>
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<td>10月</td>
<td>505</td>
<td>-9.9937</td>
<td>1.720621</td>
<td>-12.255</td>
<td>-6.085</td>
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<tr>
<td>5月</td>
<td>115</td>
<td>-18.04</td>
<td>1.495122</td>
<td>-19.771</td>
<td>-14.091</td>
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<tr>
<td>10月</td>
<td>225</td>
<td>-9.5389</td>
<td>1.779337</td>
<td>-11.847</td>
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<tr>
<td>5月</td>
<td>120</td>
<td>-14.271</td>
<td>2.215782</td>
<td>-18.666</td>
<td>-15.019</td>
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<tr>
<td>2007年 3月</td>
<td>151</td>
<td>-14.549</td>
<td>2.34023</td>
<td>-17.971</td>
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<tr>
<td>10月</td>
<td>96</td>
<td>-10.216</td>
<td>1.946038</td>
<td>-11.712</td>
<td>-7.639</td>
</tr>
</tbody>
</table>

洞里萨湖水位呈年际周期性波动

2008年平均水位较2004年的平均水位变化了5.0m左右，2006年5月份水位上升较明显

表中均值代表湖面的平均高程值即每年当月的高程值

最值分别为GLAS点中的最大、最小高程值
旱季，水面从北向南持续升高，2005-2006-2008年水位升高，其中2008年2月份水位最高


年际，水位从北到南呈上升趋势，5月份不明显可能和季节有关
The first inversion of surface deformation using 42 scenes of TerraSAR-X images (3m) in the observation period of 2011-2013. Although it is significant, the motion of relics and its surroundings is hampered by other movements triggered by urbanization, farming as well as surface erosion after wild-fires.
Through the discussion with staffs from APSARA and field investigations, causes of temple collapse have been confirmed, including erosion, tree growth and motion heterogeneity.
An improved PSInSAR model for the motion anomalies detection.

Local ground sinking intersperse among the site (with values ranging from -15 to -2 mm/a) due to urbanization and groundwater pumping, marked by “1, 2 and 3”.
Research Progress:
Ground Subsidence Monitoring

Temple-level monitoring, e.g. Bakong Temple
A. 3D Modeling & Models Collecting

- **3D Modeling by multi-source data**
  - Rebuild 3D models based on different multi-source data, such as pictures, videos, CAD data, photogrammetric data.

- **Models Collecting**
  - Collect some shared elements and models from the Internet to provide material for the 3D simulation system.
B. Design and Implementation of Spatial Database

- Designed and implemented the spatial data tables of remote sensing images, vectors and 3d models of Angkor Site.
- Stored the current multi-source data.
- Developed some database functions, such as information querying.
C. System Implementation and Preliminary Simulation

Research Progress:
3D Simulation and Spatial Information System

Main form of REAS
Terrestrial Laser Scanning for 3D reconstruction of Ta Keo temple

- Range: 1km (max.)
- Pulse frequency: 222k (max.)

Research Progress:

3D Simulation and Spatial Information System
Data Collection

- RS data: 30m DEM, Landsat images
- Historical maps: Angkor area during the 9th-14th centuries

References:

- The natural environment and historical water management of Angkor
- The development of the water management system of Angkor a provisional model
- ……
Research Progress: Ancient Water System Reconstruction

SPOT-5 image

NDWI

Decision Tree

Improved DT
Research Progress: Ancient Water System Reconstruction

Preliminary Comprehensive Map of Water-Road-Resthouse-Temple in Angkor Based Multi-Source Data
Exchange of Visit

12. 2013
03.2014
05. 2014
06.2014
07.2014
Exchange of Visit
Exchange of Visit

June 2014 LUCC & land subsidence validation
Exchange of Visit
Virtual Satellite Receiving Station
Thanks