REALITY-BASED 3D MODELING WITH PHOTOGRAMMETRY AND LASER SCANNING
- LATEST DEVELOPMENTS AND APPLICATIONS -

Fabio Remondino
3D Optical Metrology (3DOM) Group
Bruno Kessler Foundation (FBK), Trento, Italy
http://www.fbk.eu
remondino@fbk.eu

Contents:
- Reality-based 3D modeling
- Photogrammetry
- Laser scanning
- Sensor integration
- Automation issues
- Examples of large and complex sites
- Conclusions

3D MODELING CONCEPT

- Object 3D modeling is the process of developing a mathematical (e.g. wireframe) representation of any three-dimensional object (either inanimate or living) using specialized software and techniques.
- 3D modeling can be performed with various types of data and using different techniques (e.g. photogrammetry) or a combination of them ("methodology").
- 3D modeling most requested product: structured 3D data and textured 3D models.
- Intermediate results/products: unstructured 3D data (point clouds), vector and raster data, etc.
- 3D modeling includes and precludes knowledges of sensor modeling (camera calibration, pose estimation, sensorcharacterization, etc.), sensor & data integration, terrain/surface modeling, appearance modeling (radiometric corrections, blending, reflectance mapping, global illumination, etc.).
### REALITY-BASED 3D MODELING

<table>
<thead>
<tr>
<th>Platforms</th>
<th>Sensors &amp; Wavelength</th>
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<tbody>
<tr>
<td>800 km</td>
<td>+ satellite + x-ray</td>
</tr>
<tr>
<td>altitude</td>
<td>+ airborne + UV</td>
</tr>
<tr>
<td>1-10 m</td>
<td>+ balloon – UAV + visible</td>
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<tr>
<td></td>
<td>+ terrestrial + IR (near and thermal)</td>
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<td></td>
<td>+ underwater + radar</td>
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**Platforms:**
- 3D modeling with satellite, airborne, balloon - UAV, terrestrial, underwater platforms.

**Sensors & Wavelength:**
- X-ray, UV, visible, IR (near and thermal), radar.
- Wavelengths: ca 0.01 nm, >1 cm.

### Image-based techniques (passive sensors)
- Photogrammetry, computer vision, shape from X, etc.
  - Satellite, aerial, terrestrial platforms
  - Dense or sparse point clouds
  - Quite cheap but experience required

### Range-based techniques (optical active sensors)
- Laser scanners, stripe projection systems, etc.
  - Aerial or terrestrial platforms
  - Triangulation vs time-delay measurement principle
  - Dense 3D point clouds
  - Fast & easy to use but expensive & bulky

### Surveying methods
- Total station, GPS, maps, etc.
  - Sparse points, low density and resolution, time consuming

### Procedural modeling

### Computer graphics (3DStudio, Maya, Sketch-up, etc)
Techniques: photogrammetry, computer vision, shape from X, etc.
Satellite, aerial, UAV, terrestrial, underwater platforms
CCD/CMOS sensors based on frame or linear array geometry
Images provide for 3D shape and texture
Known distance to get metric results
Mathematical model required to transform 2D image observations in 3D information
Automated procedures for quick results useful mainly for VR, visualization, etc
Interactive procedures for accurate results useful for mapping, documentation, physical replica, conservation, restoration, etc.

POTENTIALITIES OF IMAGE-BASED TECHNIQUES

- High accuracy
- Portability (terrestrial)
- Flexibility
- Fast acquisition
- Large availability
- Low cost (terrestrial)

**Photogrammetry**
“the art of turning 2D images into 3D models, keeping an eye on the accuracy and completeness of the results”
3D MODELING with PHOTOGRAMMETRY

- Satellite, aerial, terrestrial, underwater platforms and images
- Data in the visible, UV, IR, x-ray spectral domain
- Achieved 3D results are
  - Complete: geometry + texture
  - Metric: measurable and possibly geo-referenced
  - Detailed: no smoothed surfaces, all the features are correctly modeled
  - Accurate: precision + reliability
  - Photo-realistic: high resolution texture
- Accuracy ranges: few cm down to few microns (1:10 000 – 1:1 000 0000) and generally sub-pixel accuracy
- Interactive measurements are not denied
- Automated approaches (e.g. image orientation or image matching)

Typical photogrammetric domains:
- Mapping / cartography
- Heritage documentation
- Physical replica
- Digital conservation
- Digital restoration
- Large site 3D modeling
- Deformation analysis
- Animation (MOCAP)
- etc.

Requirements:
- At least 2 images from different viewpoints
- A known distances of points with known 3D coord.
Always separated procedure, self-calibration is not enough precise and always reliable in practical cases

- **Camera calibration** (interior parameters):
  - coded target and Least Squares template matching to get sub-pixel accuracy (>1/25th of a pixel)
  - 3D testfield + rotated images for reliable determination of all the interior camera parameters (10 Additional Parameters)

- **Image orientation** (exterior parameters):
  - Generally performed manually due to a lack of automated commercial procedures
  - Already solved some years ago in the CV community but no accurate and commercial solution

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Interactive 3D reconstruction in case of architectural features, man-made objects with simple structures, planar façades, accurate city models, semantic classification, etc.

- Fully automated procedures are still not yet completely reliable and precise in practical applications.
- Intelligent procedure which combines the human capacity in image content interpretation paired with the speed and precision of computer-driven measurement algorithms.


- Bamiyan Buddha statue, 56 m high, destroyed in 2001 by the Taliban.

- 3D reconstruction from archive images with 2-3 cm accuracy (>1:4000) for:
  - Physical replicas (scale 1:25, 1:200) and possibly onsite
  - Documentary movie

The Giant Buddhas movie (www.giant-buddhas.com)

August 2003 Virtual Reality

- Aerial & terrestrial images, old maps, GPS
- Ca 1 month/castle (1 person)
- Achieved relative accuracy (Valer castle, ca 70x40m, 35m height): 17mm (X), 15mm (Y), and 16mm (Z)
- VR, animation, conservation issues, entertainment, etc.
“Spherical photogrammetry”
Collinearity principle re-written in spherical coordinates
Very high-resolution images obtained stitching multiple images

Plaza de Armas, Cuzco (Peru), 13 panoramas
**INTERACTIVE 3D MODELING FROM PANORAMS**

- 17 spherical panoramas of the interior
- 4 spherical panos for the façade
- 5 spherical panos for the roof

Architectural drawing (1:50 scale) needed for studies and restoration

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**3D MEASUREMENTS - AUTOMATIC**

- Automated reconstruction for objects with free-form shapes and many discontinuities
  - Image matching and dense point clouds generation
  - Multi-image approach (after Zhang, 2005) => simultaneous matching of more than 2 images and direct computation of the object coordinates
  - Combination of multiple primitives (interest points, grid, edges)
  - Epipolar resampling to face the image convergence and scale differences
  - Precise feature location by LSM algorithm
  - Tie points of the orientation phase as initial guess of the surface to be matched
  - Multiple epipolar images & DSM in each pyramid level to constrain the search
  - Higher redundancy and reliability compared to classical stereo approaches

AUTOMATED 3D RECONSTRUCTION

- 3 widely separated images

- 5 separated images


F. Remondino - REALITY-BASED 3D MODELING WITH PHOTOGRAMMETRY and LASER SCANNING

[ca 2 meters]

[130 mm focal length]

[object size ca 2 x 1 x 0.5 m]

[object-camera distance ca 20 m]

[3D comparison with laser scanner data - Leica HDS 3000 ($\sigma = 6$ mm @ 50m) revealed 3 mm std]
**AUTOMATED 3D RECONSTRUCTION**

- 3D comparison with range data acquired with a Breuckmann system (patter projection, 50 μm feature accuracy)
- The std of the differences between the 2 surface models results approximately 0.17 mm

**SEMI-AUTOMATED 3D RECONSTRUCTION**
Photonometric 3D Reconstruction

With photogrammetry you can easily decide to get sparse 3D point clouds (e.g. for building 3D modeling) or dense point clouds (e.g. for bas-relief or decorated areas).

Rideau channel house, Ottawa, Canada

Decorated door frame of the Eumachia building in Pompeii

Reality-Based 3D Modeling

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- Surveying methods
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- Procedural modeling

- Computer graphics (3D Studio, Maya, Sketch-up, etc)
+ Fast, easy to use, great quantity of data, many packages to process the data
- Heavy, very expensive, difficulties in transportation, dedicated range, no/low texture

**Optical range sensors**

- Triangulation: Pattern Projection, Laser light
  - Time delay: Time-of-flight, Amplitude modulation
  - Range: <2 m
  - Accuracy: 50~200 μm

- Range: 1-10000m
- Accuracy: 2-3 mm to few dm

**RANGE-BASED MODELING PIPELINE**

- ‘Range Measurements’ (+intensity) → 3D Point Cloud
- Registration
- Mesh generation (surface triangulation)
- 3D Object / Features reconstruction
- Bronze monument of A. Escher, founder of Credit Suisse, ETH University and Gotthard railway
- Scanning during 3 nights to avoid traffic
- FARO scanner
- 6 days of data processing
Digital Mona Lisa, for conservation and preservation purposes (60 micron geom. resolution)

Mona Lisa (NRC Canada)

INTEGRATED TECHNIQUES

- The integration of sensors and data is the state-of-the-art for 3D surveying and documentation, in particular for large and complex sites
- Passive and active sensors as complementary techniques
- Sensors and data integration to:
  a) employ the most suited surveying method for each object contained in the area under investigation and derive the most adequate level of information;
  b) introduce a level of redundancy in the acquired data useful (i) to optimize the model accuracy, (ii) identify possible metric errors in the model and (iii) seamlessly merge the boarding areas at different geometric resolution;
  c) fulfill all the measurement and surveying needs and requirements
  d) introduce different levels of detail in geometry and texture for further visualization issues
- Research issue: data integration to overcome problems and surveying difficulties of the methodologies (e.g. laser scanning on the edges or photogrammetry on textureless areas)
For large sites, the best choice is the integration of multiple techniques and data.

- **Data selection**
  - Digital images
  - Range data
  - GPS / Surveying / Maps

**Requirements**
- Details, accuracy, time, location, etc...

**Further products**
- Replicas, conservation plans, animations, databases, etc.

**Integrated Technique**

**Image Data**
- Calibration, orientation, manual measurements, dense matching
- Editing, registration, noise/overlap reduction

**GPS / Maps / Total Station**

**Range Data**

**Sparse or Dense Point Clouds**

**Geometric Modeling**
- Data integration, structuring, mesh generation and simplification, overlap reduction, holes filling, segmentation, primitive fitting, etc

**Appearance Modeling**
- Texture and bump mapping, radiometric corrections, blending, reflectance mapping, global illumination, etc

**Detailed and Photo-Realistic Textured 3D Model**

**Rendering and Visualization**

[Remondino, F., El-Hakim, S., Girardi, S., Rizzi, A., Benedetti, S., Gonzo, L., 2009: 3D Virtual reconstruction and visualization of complex architectures, ISPRS 3D-Arch Int. Workshop 2009, Trento, Italy]
3D MODELING with INTEGRATED TECHNIQUES

- 3D Modeling of the roman forum in Pompeii, Italy
  - GPS surveying for geo-referencing
  - Aerial images for low-resolution DSM (1:3500 scale, 5 cm GSD)
  - 1.2 bil. terrestrial laser scanner points for middle resolution modeling
  - Ca 5000 images for photogrammetric detailed 3D reconstruction
  - Geometric resolution from 20 cm to 0.5 mm
  - Segmentation of each 3D model and linking to an existing archaeological database


- Buonconsiglio Castle, Trento, Italy
  - Loggia full of frescos
  - Ca 30x10m wide and 12 m high
  - Integration of laser scanner, photogrammetry and surveying
  - Visualization, documentation, fruition, virtual interaction, web, etc.
CONCLUSIONS

- Reality-based 3D reconstruction from images
- Accurate, complete, metric and detailed results using photogrammetry
- Interaction still mandatory for different applications
- Automation feasible in different reconstruction phases
- Fully automated methods are not applicable in most of the practical situations
- Image-based methods need often to be combined with other surveying techniques for large and complex sites
- Open research issues:
  - Better image interpretation / understanding to reduce user intervention for precise and reliable feature extraction (e.g. building/architecture 3D modeling, 3D road vectors, etc.)
  - 4D modeling (inclusion of dynamics and processes)
  - Efficient method for handling the great inflation of data (images, raster, vector, metadata, etc.)
  - Seamless integration of geospatial data coming from different sensors, at different geometric and radiometric resolution, different acquisition time, etc.