Digitizing Seals

An introduction to RTI
in sigillography

Marcel Schaeben, CCeH, University of Cologne
m.schaeben@uni-koeln.de

Simona Stoyanova, LatinNOW, University of Nottingham
simona.stoyanova@nottingham.ac.uk

Martina Filosa, University of Cologne
martina.filosa@uni-koeln.de

SigiDoc & RTI-dome in action
20-21 January 2020
Venice Centre for Digital and Public Humanities
Ca' Foscari, University of Venice

Reflectance Transformation Imaging (RTI)

- Taking **multiple digital images** of an object from **different lightning angles**

- Process them to **produce interactive "relightable" images** with a movable virtual light source

- Mathematically enhance the image to bring out **fine details of the surface structure**

- First developed at HP labs in 2001 as „Polynomal Texture Mapping" (PTM)
  Malzbender, Tom, Dan Gelb, and Hans Wolters. "Polynomial texture maps." Proceedings of the 28th annual conference on Computer graphics and interactive techniques. ACM, 2001.

- Developed further mainly at the non-profit *Cultural Heritage Imaging (CHI)* and *Istituto di Scienza e Tecnologie dell'Informazione "A. Faedo" (ISTI-CNR)*
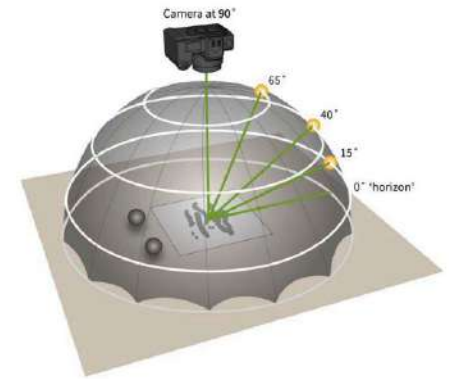
RTI – Advantages

- Brings out fine details of the physical structure
- Improve legibility
  - Previously illegible text can be deciphered
- Non-degrading process
- Scalable and flexible
- Documentation, preservation and conservation
  - Objects do not need to be handled to study them
  - RTI Viewer tools allow documentation and exact reproduction of viewing conditions
- Visually engaging online presentation
  - For collections, museums etc.

Theory – Polynomal Texture Maps (PTM)

Bitmap: stores three **color values** per pixel (red, green, blue)
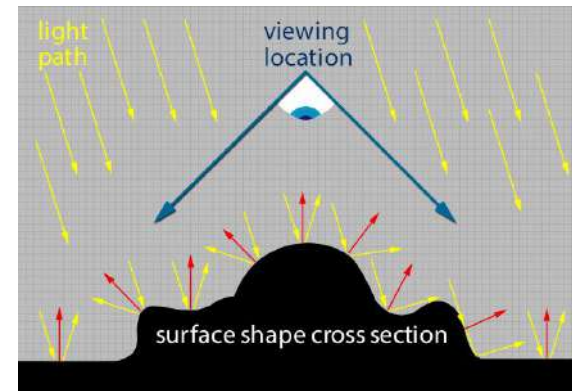
RTI: in addition to color information, store also **shape information**

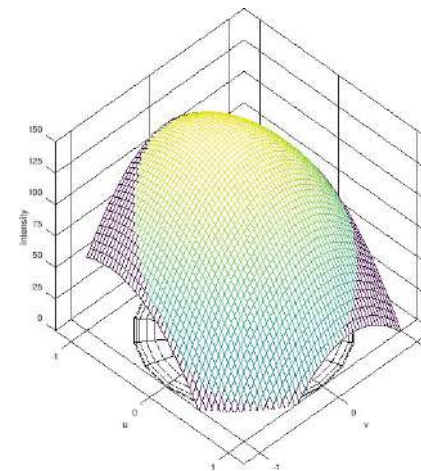We want to reproduce h**ow incoming light reflects** on the object for each point of the surface
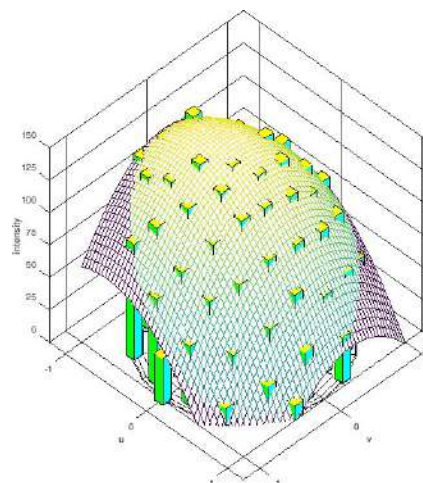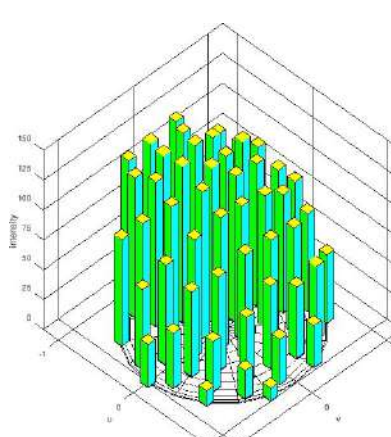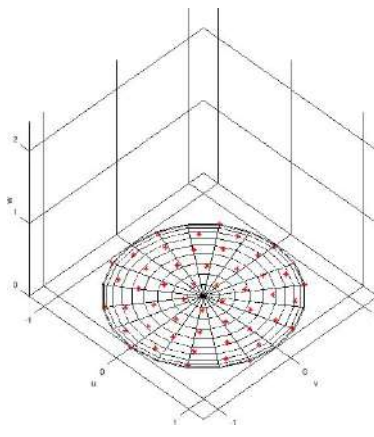
Our source material: multiple image of the object from **various lighting angles**
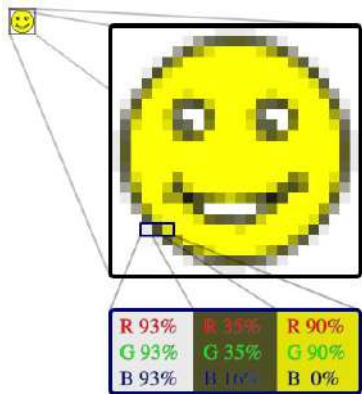
raster graphics
(image: Wikipedia)

red arrows are called *normal vectors*
(image: CHI)

Theory – Polynomal Texture Maps (PTM)

- Generating PTMs
  - for each pixel find an equation that, when you put in the coordinates of each light source, returns the luminance value recorded when lit from that source
    - eg. 0 (black) – 255 (white)
  - for each pixel, store that equation

- Viewing PTMs
  - user chooses a light position
  - for each pixel, put those coordinates into the stored equation

*the bars are the luminance for **one specific pixel** at 60 lightning angles*

***PTM fitter** finds 6 factors:*

$x_0 - x_5$
stored for each pixel

light coordinates between the actual 60 LEDs are interpolated: light source can be moved continuously!

$(u, v) \longrightarrow$ $b = x_0u^2 + x_1v^2 + x_2uv + x_3u + x_4v + x_5$

= coordinates of the light source

https://cceh.github.io/rti/intro.html

Highlight Method

Photo: Kathryn Piquette

+   cheaper
+   easier to transport
+   allows imaging of large scale objects, e.g. walls
+   manual tinkering with parameters

-   imaging takes longer
-   post-processing needed
-   easier to make mistakes

Highlight method: kit

Photo: Cultural Heritage Imaging

- spheres
- finish washers for holding spheres
- threaded rods
- coupler nuts

- umbrella adapter handle with flash mount
- handle matched with coupler to mount umbrella adapter
- coupler adapters
- Threaded stems to hold radio trigger or to secure string
- OP-3 – UV-filtering acrylic

- string for measuring a fixed distance from target to light source
- bongo ties for cable management
- bubble level – fits on SLR

Highlight method: setup

- tripod + sandbags
- sturdy ball head to hold weight of the camera + flash
    - UV filter on the lens – cheaper to replace than the lens if scratched
- lens:
    - avoid zoom: lens can slip – tape it in position but it can lose focus
    - 50 mm, minimal distortion
    - no wide lenses!
- camera square to the target
- set to shoot on raw, connect to 4-5 m cable to laptop
- transmitter, flashgun – add a handle for convenience, have an extra battery pack on hand
- balls
    - ceramic better than steel
    - only the 1/3 top of the ball is above the object, the diameter should be fully visible
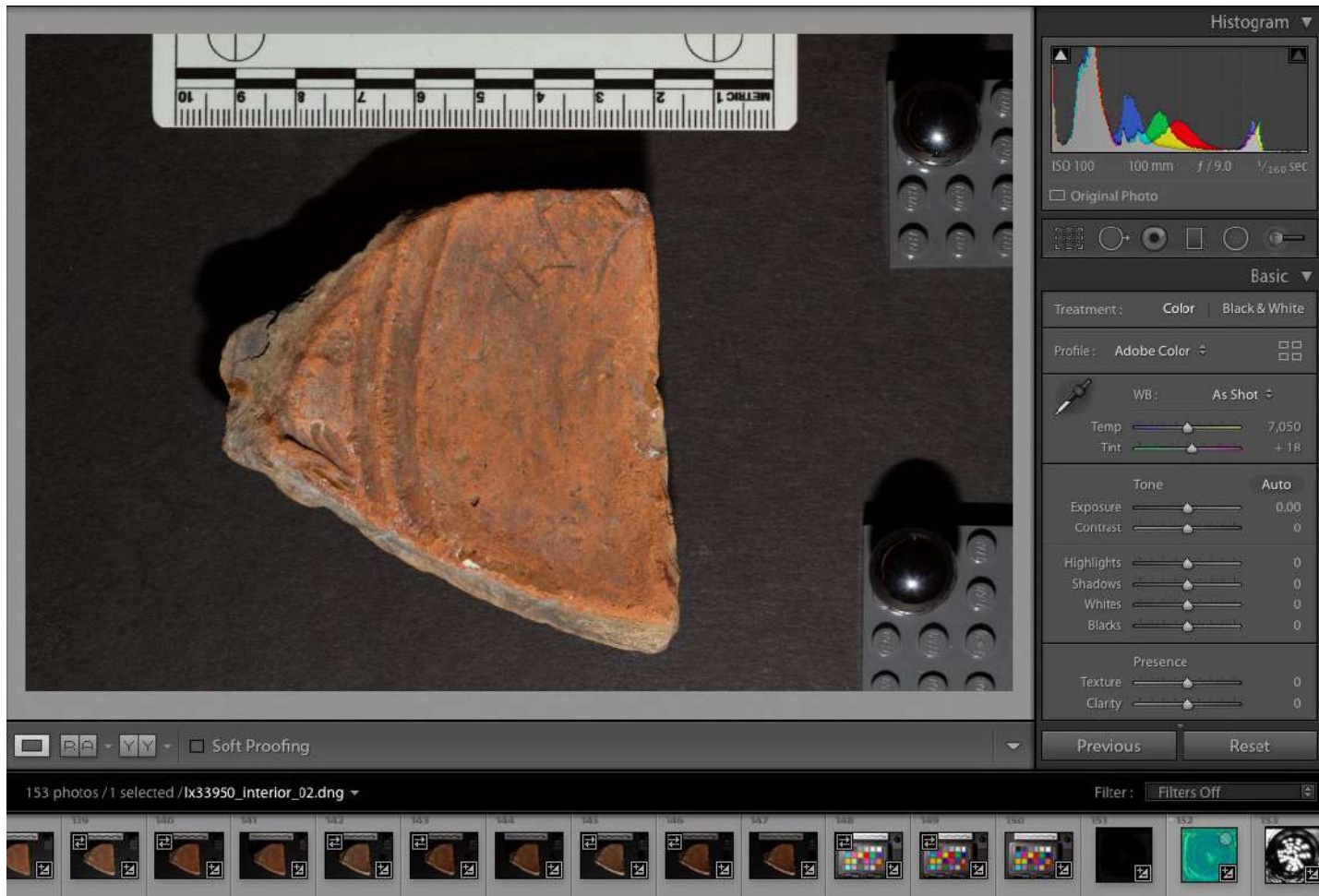
Highlight method: capture

- light source – distance, position, angle

  - the longest distance – 3-4 times the distance in any direction

  - test shots at 65° and 15° with the flash; change aperture if overexposed

  - background – black/white; back-up fabric too; Legos !

  - adjust the camera before the object is brought in – don't drop it on the object !

- 36-48 images per object; each rib from 65° to 15°

- colour palette – 2-year lifespan, put the date of first use on it; don't touch the colour patches

- tie string to the flash, other end is the flash trigger

- shoot the colour patch with the same settings

- shooting log – string length, setup, automatically collected info; no full-stop or space in filenames !
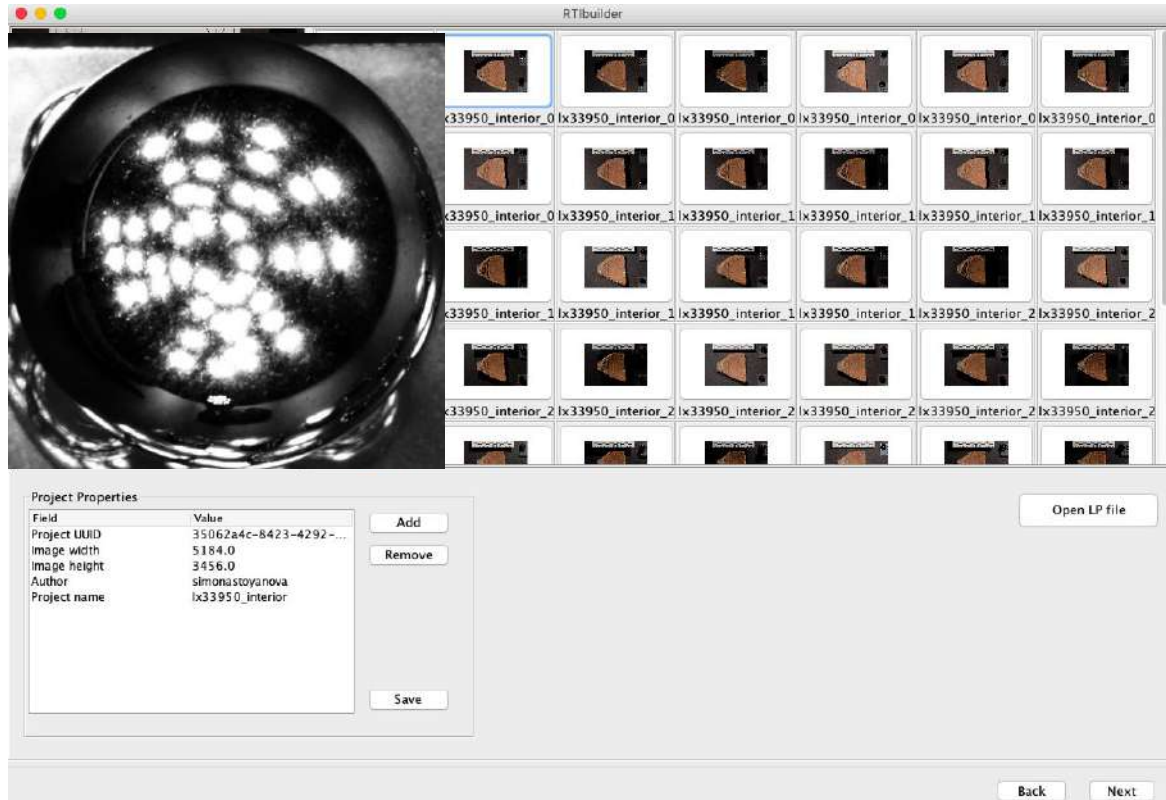
Highlight method: processing

Adobe Lightroom Classic

- review the captured images for usability

- check focus

- lens correction if needed

- adjust white balance if needed

- convert from camera-raw to DNG format for archiving

- convert from camera-raw to JPEG format for further processing

Highlight method: processing

RTI Builder

- add metadata about project, team, settings, removed images
- remove colour chart, document it !
- metadata automatically added to an XML file
- process the JPEG image set to produce an RTI file
- highlight detection on a sphere - how to process the entire set
- crop the spheres, leave the scale
- process in .ptm format for viewing in the RTI Viewer
- produce a TIFF for publication

Highlight method: applications

- Rock art
- Inscribed walls
- Large objects
- Immovable objects
  - location
  - permissions
  - fragility

Photo: Cultural Heritage Imaging

Taking it further

- arc can be used too, moving it around to replicate dome array

- can combine multispectral and RTI – spectral RTI

- different needs – legibility, production and ducts, damage, surface changes

- Herculaneum papyri – carbon ink absorbs IR, carbonised papyrus reflects it black

- Vinolanda tablets - discolouration of surface

Dome Method

- Fixed array of lights

- Automatic operation

+ more precise lighting

+ easier to operate

+ speed! (2-3 min vs. 15min up to ~1-2 hrs per object)

+ easily operated by one person

+ no need for spheres

- more expensive
- object size constraint
- less mobile

Dome Method – Examples

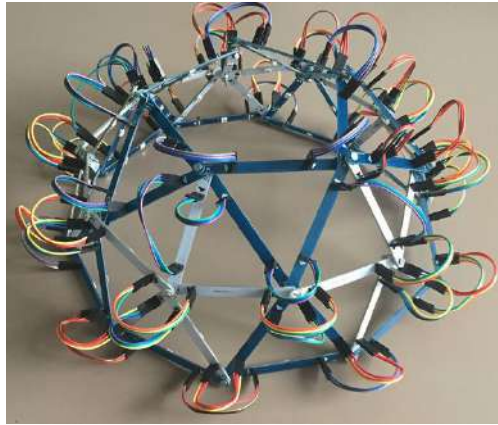Dome in the field (Leszek Pawlowicz)

Dome with camera rig (Graeme Earl)
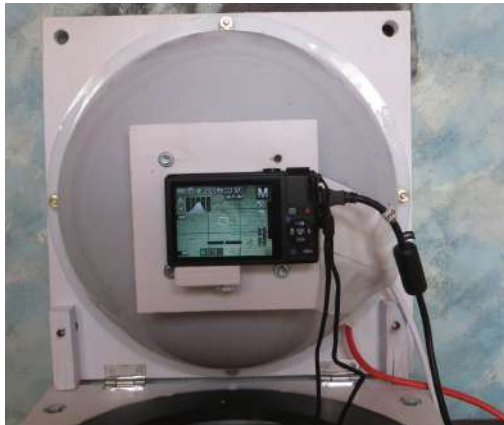
Dome in vertical mode
(Leszek Pawlowicz)

Dome made from circuit boards
(Tim Zaman)

Dome of Santa Cruz University's Graphics
and Motion Capture Lab (1.5m)

The CCeH Dome

The CCeH Dome

- Based on the [DIY design by Leszek Pawlowicz](), adapted by Marcello Perathoner (CCeH) [https://cceh.github.io/rti/builder.html]()

- 50 cm circumference

- Max. object size (depending on lense focal length):

Focal Length (mm)	Width (cm)	Height (cm)
105.00	8.57	5.71
60.00	15.00	10.00
35.00	25.71	17.14

[https://cceh.github.io/rti/lens_selection.html#object-sizes]()

Building the Dome

Building a Dome – Cost & Requirements

- Around 300€ of materials and services (excluding tools)
  - Will vary by country and exact materials used
  - The original instructions by Leszek Pawlowicz say 600$ (~550€)

- Suitable Camera
  - We use a Nikon D800 which was about 3000€
 - Cheaper cameras can be used

- Someone with good knowledge of electronics
  - Or someone with interest and a lot of time to learn!

- Around 50 working hours (very optimistically)
  - Assuming electronics geek on-site

- Access to tools (soldering iron, hand/bench drill, hole saw…)
  - We went to a local maker space for cutting the camera hole
  - Controller circuit board etching was „outsourced"
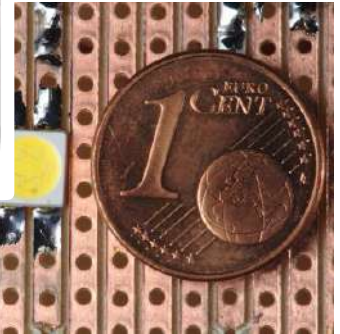
LEDs, ~50€

Dome, ~80€

Controller board & case, ~80€

and cables, screws, handles, spray paint, ac adaptor, …

„No way… " – RTI Options for your project

- Build a dome anyway – ideas
  - Dome building can be part of funding applications
  - Look for institutions with a dome and ask if those who built it can be contracted
  - Ask around – is there a secret electronics hobbyist at your institution? Do you have an archeology/archeo-informatics department at Uni or similar for possible cooperations?
- Have a custom Dome built
  - Southampton University, medium sized dome around 10.000
- Get Highlight RTI training and equipment
  - Equipment is 370$ and can be ordered from CHI (RTI Starter Kits)
  - Training can be obtained from Kathryn Piquette at UCL (£1,200)
    https://www.ucl.ac.uk/short-courses/search-courses/reflectance-transformation-imaging-rti-training
- Cooperate with external institutions that have a Dome
  - I know of one… CCeH is always interested in cooperations :)
  - Look for joint / international funding programmes from your local research institutions (eg. ANR-DFG for France/Germany)

More funding ideas

- Citizen Science
  - Austrian Academy of Science had school kids build a dome [https://www.oeaw.ac.at/oeai/kommunikation/presse/press emitteilungen/pa-20180813-rti-dome/](https://www.oeaw.ac.at/oeai/kommunikation/presse/pressemitteilungen/pa-20180813-rti-dome/)

- Crowdfunding
  - The Balkan Heritage Field School raised 4000€ of donations for building a dome [https://www.bhfieldschool.org/news/rti-dome-campaign-su ccessful](https://www.bhfieldschool.org/news/rti-dome-campaign-successful)

Viewing

RTI Viewer by CHI – Rendering Modes (examples)

Default (no filter)	**Diffuse gain**	**Specular enhancement**	**Normal unsharp masking**	**Normals visualization**

Diffuse gain and specular enhancement described in original Malzbender (2001) paper.
Details about all filters in the RTIViewer docs:
http://culturalheritageimaging.org/What_We_Offer/Downloads/rtiviewer/RTIViewer_Guide_v1_1.pdf

increases the representation of quickly-changing height and depth on the subjects surface

modifies reflectance properties –
works good for shiny materials (metal, glazed pottery), not with translucent materials

sharpening of edges using surface data by increasing edge contrast

show pure surface data – color visualizes surface orientation

Download: http://culturalheritageimaging.org/What_We_Offer/Downloads/View/index.html

Processing images into PTMs

- RTI Builder by CHI
  http://culturalheritageimaging.org/What_We_Offer/Downloads/Process/

  - **Generates LP file** from spheres
  - Allows to **crop** and **resize** all pictures
  - Needs the PTMFitter command line tool from HP
    - Not available directly from HP anymore, for the time being find it here
      http://forums.culturalheritageimaging.org/topic/615-ptmfitter-software-download-link/

  - Has some quirks (does not allow file / path names with spaces etc.), read the detailed manual carefully
    http://culturalheritageimaging.org/What_We_Offer/Downloads/rtibuilder/RTI_hlt_Processing_Guide_v14_beta.pdf

- Alternative processors (work-in-progress, command-line, only PTM generation, need existing LP file for Dome or similar)
  - https://github.com/cnr-isti-vclab/relight
  - https://github.com/cceh/rti

Publication of RTI images

- PTMs to download
  - large file size
  - needs dedicated RTI Viewer application installed on the user's computer

- WebRTIViewer by CNR-ISTI Visual Computing lab
  http://vcg.isti.cnr.it/rti/webviewer.php
  - Generates web site fragments with a RTI viewer for one specific PTM to embed in web sites and display and manipulate lighting directly in the browser
  - Images need to be pre-processed into a special web format
  - Lower quality (but loads quicker)
  - No filters / enhancements
  - Successor in development: relight.js (works well already!)
    https://github.com/cnr-isti-vclab/relight

WebRTIViewer with papyrus from the Magica Levantina project (CCeH)

RTI-Ansicht des Siegel des Alexios, Mönch, Erzbischof von Zypern und synkellos (5-118 Avers, Sammlung Robert Feind, Köln). Mit gedrückter Maustaste über das Bild fahren, um den Belichtungswinkel zu verändern.

relight.js embedded into a blogpost on the CCeH website
https://cceh.uni-koeln.de/2019/04/26/rti-dome-am-cceh-erster-testlauf-erfolgreich-absolviert/

relight.js in normals visualization mode

RTI & SigiDoc?

- RTI images could be embedded in SigiDoc metadata

- Integration into EFES or another frontend system
  - using relight.js?

```
▼<tei:facsimile>
 ▼<tei:surface type="ptm">
   <tei:graphic url="BM/1891_4-18_17_front_cropped_3310.ptm"/>
   <label xmlns="http://www.tei-c.org/ns/1.0"/>
  </tei:surface>
 ▼<tei:surface type="ptm">
   <tei:graphic url="BM/1891_4-18_17_back_cropped_3193.ptm"/>
   <label xmlns="http://www.tei-c.org/ns/1.0"/>
  </tei:surface>
 ▼<tei:surface type="picture">
   <tei:graphic url="1891,4-18.17.jpg"/>
   <label xmlns="http://www.tei-c.org/ns/1.0"/>
  </tei:surface>
 </tei:facsimile>
```

- In the Magica Levantina project at CCeH, we reference RTI PTMs just like normal images

- On the collection website, the URLs can be used to generate a download link for the PTMs

- For display in the browser, PTMs have to be pre-processed manually or automatically.

- In Magica Levantina, web versions have been generated automatically using a script

Alternatives to RTI – 3D scanning

- exact shape information
- manipulatable 3D models
- objects can be replicated (3D printing)
  - also at different scales, materials, colors…

- relatively expensive
- models need to be tweaked in 3D editing software
- problems with reflective surfaces
- low quality texture and color in lower price segments
- limited to small to medium sized objects
- highly controlled environment needed (no daylight)

NextEngine 3D laser scanning. Photo: White, Suzanna (2015). Virtual Archaeology. Archaeology International, No. 18: pp. 41–44,
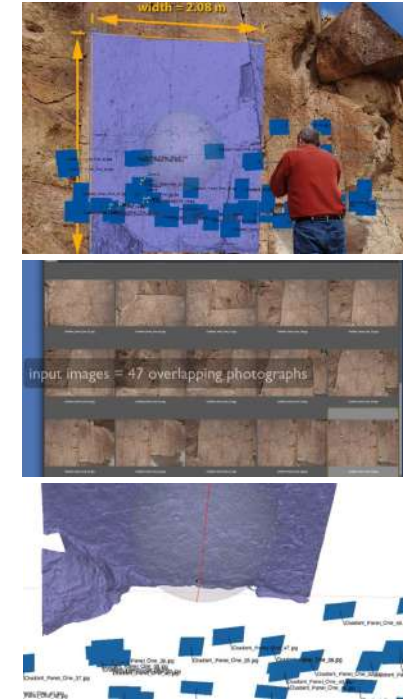

Cuneiform 3D scan (Mara & Bogacz, Heidelberg University).

Moshe Caine and Michael Magen. 2017. Low cost heritage imaging techniques compared. In Proceedings of the conference on Electronic Visualisation and the Arts (EVA '17). BCS Learning & Development Ltd., Swindon, GBR, 430–437. DOI:https://doi.org/10.14236/ewic/EVA2017.85

Alternatives to RTI – Photogrammetry

- take multiple overlapping photographs of an object from different directions
- process them into 3D models, cleaning
- scalable up to almost any size

- problems with reflective and transparent images, shadows
- less effective for very fine surface details
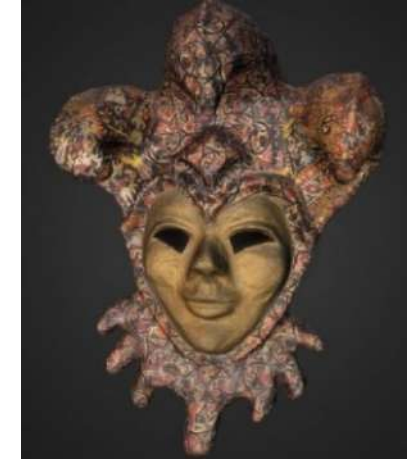
Caine & Magen (2017): venetian mask

CHI: Photogrammetry for Rock Art
https://vimeo.com/99187767

http://culturalheritageimaging.org/Technologies/Photogrammetry/

Alternatives to RTI

Hellenistic steele (stone)
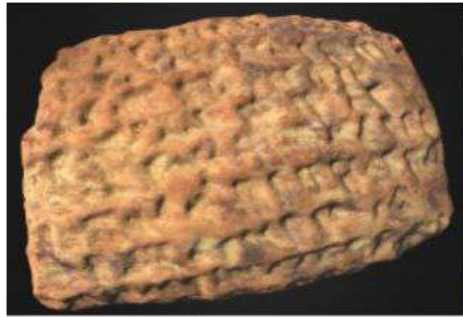

Roman coin (laser scan)
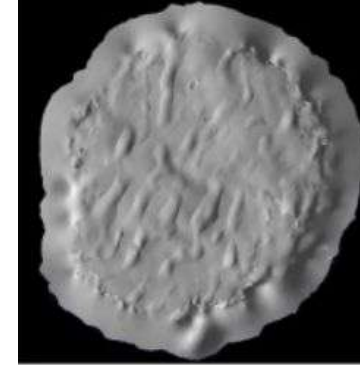
Sumerian tablet (clay)

Roman coin (RTI)

Moshe Caine and Michael Magen. 2017. Low cost heritage imaging techniques compared. In Proceedings of the conference on Electronic Visualisation and the Arts (EVA '17). BCS Learning & Development Ltd., Swindon, GBR, 430–437. DOI:https://doi.org/10.14236/ewic/EVA2017.85

Alternatives to RTI

DIY 3D printed "3D scanner" / photogrammetry rig

https://www.openscan.eu/

https://www.thingiverse.com/thing:3050437

Resources

- Cultural Heritage Imaging
  http://culturalheritageimaging.org/Technologies/RTI/

- RTI Theory & Math by Marcello from CCeH
  https://cceh.github.io/rti/intro.html

- Exhaustive RTI booklet by Historic England
  https://historicengland.org.uk/images-books/publications/multi-light-imaging-heritage-applications/heag069-multi-light-imaging/

- Aggregate collection of cuneiform tablets with RTI web viewer for some records
  https://cdli.ucla.edu/search/search_results.php?SearchMode=Text&ObjectID=P272825

Acknowledgements

LatinNow