

Photographic 3D scanning in the wild

Benjamin Coupry¹, Antoine Laurent¹, Jean Mélou¹, Yvain Quéau², Jean-Denis Durou¹

¹ IRIT, UMR CNRS 5505, Université de Toulouse, France

² GREYC, Université de Caen, France



GREYC
Electronics and Computer Science Laboratory

Table of content

3D digitization of heritage

Calibrated photometric stereo

Self-calibrated photometric stereo

Locally self-calibrated photometric stereo

Case of the Pech Merle cave painting



“Panneau des chevaux ponctués” (Pech Merle cave, Lot, France)

3D digitization of heritage

Calibrated photometric stereo

Self-calibrated photometric stereo

Locally self-calibrated photometric stereo

Two main expectations

- For archeological purposes
 - Digital preservation for conservation
 - Long-term archiving
 - Analysis
- For public purposes
 - Accessibility to the greatest number of people (ex: museography)
 - Realistic “digital twins”

Two families of digitization solutions for surface acquisition:

- Lasergrammetry
 - Pros: fairly good geometric accuracy
 - Cons: very expensive, poor quality textures
- Photogrammetry
 - Pros: requires a simple camera, inexpensive, 3D models with better quality textures
 - Cons: increased geometric uncertainty

Needs

- Accuracy: capturing digitized tracings, fine engravings, etc.
- Separate the relief from the color: analysis of the antero-posteriority

Photometric stereo

- Have a pixel-size accuracy
- Separate light, geometry and color

⇒ Photometric stereo is the solution!

Table of content

3D digitization of heritage

Calibrated photometric stereo

Self-calibrated photometric stereo

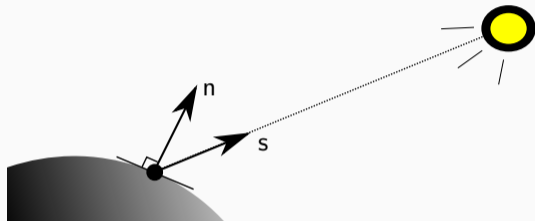
Locally self-calibrated photometric stereo

Lambertian surface

Lambert's law

$$\underbrace{I}_{\text{Grey level}} = \underbrace{\rho}_{\text{Albedo}} \times \underbrace{\max\{0, s^T n\}}_{\text{Shading}}$$

- $s \in \mathbb{R}^3$: lighting vector
- $n \in \mathbb{S}^2 \subset \mathbb{R}^3$: normal to the surface
- $m = \rho n \in \mathbb{R}^3$



Inverse image formation model

- Ill-posed problem with one image
- Photometric stereo: $n \geq 3$ images from same viewpoint under different lighting conditions

Results of photometric stereo



$$I_1 = s_1^T m$$



$$I_2 = s_2^T m$$



$$I_3 = s_3^T m$$



Albedo ρ



Normal field n



Depth map



Until now: lighting assumed to be known
⇒ Calibration by sphere

Lambert's law

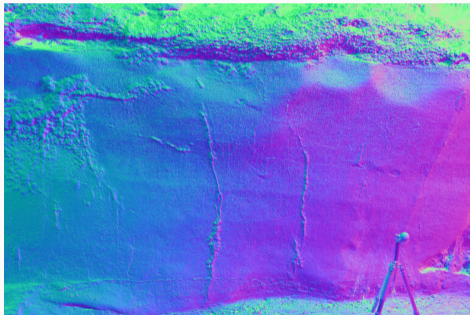
$$\underbrace{I}_{\text{Grey level}} = \underbrace{\rho}_{\text{Albedo}} \times \underbrace{\max\{0, \mathbf{s}^T \mathbf{n}\}}_{\text{Shading}}$$

- $\mathbf{s} \in \mathbb{R}^3$: lighting vector
- $\mathbf{n} \in \mathbb{S}^2 \subset \mathbb{R}^3$: normal to the surface

Calibrated photometric stereo in Pech Merle (1/2)



Calibrated photometric stereo in Pech Merle (2/2)



PS with light calibrated by sphere



Albedo

Photometric stereo in Chauvet Cave, Ardèche



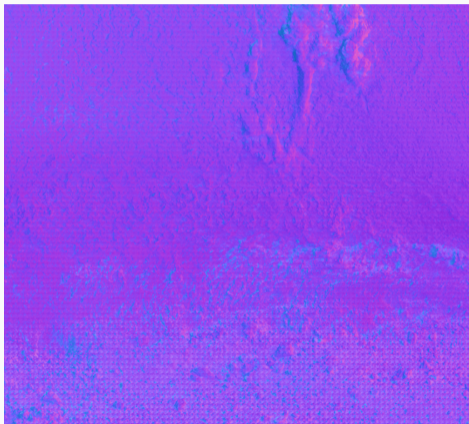
- A sphere is positioned at the end of a pole
- Position of the sphere in the image differs from one image to another

3D digitization of heritage

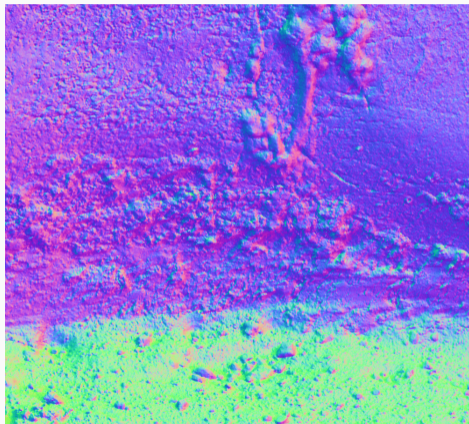
Calibrated photometric stereo

Self-calibrated photometric stereo

Locally self-calibrated photometric stereo



Normals from SDM (deep learning)



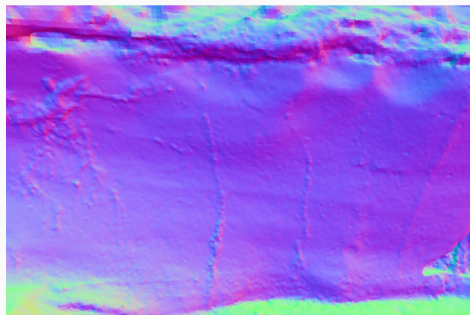
Normals from calibrated photometric stereo

Light calibration with unknown albedo (1/2)

Lambert's law

$$\underbrace{I}_{\text{Grey level}} = \underbrace{\rho}_{\text{Albedo}} \times \underbrace{\max\{0, \mathbf{s}^T \mathbf{n}\}}_{\text{Shading}}$$

- $\mathbf{s} \in \mathbb{R}^3$: lighting vector
- $\mathbf{n} \in \mathbb{S}^2 \subset \mathbb{R}^3$: normal to the surface



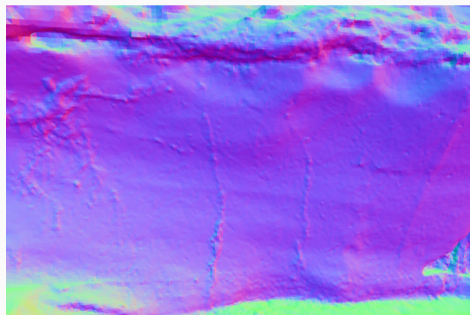
Normal field prior (multi-view)
⇒ Reliable in low frequencies

Light calibration with unknown albedo (2/2)

Lambert's law

$$\underbrace{I}_{\text{Grey level}} \times \underbrace{1/\rho}_{\alpha} = \underbrace{\max\{0, \mathbf{s}^T \mathbf{n}\}}_{\text{Shading}}$$

- $\mathbf{s} \in \mathbb{R}^3$: lighting vector
- $\mathbf{n} \in \mathbb{S}^2 \subset \mathbb{R}^3$: normal to the surface



Normal field prior (multi-view)
⇒ Reliable in low frequencies

Problem formulation

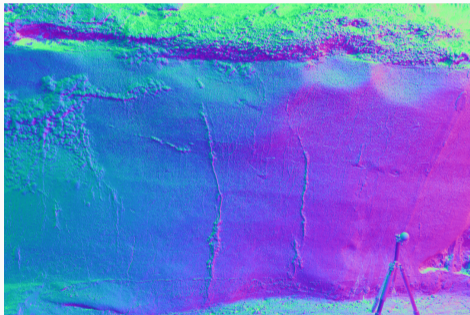
$$\begin{aligned} \min_{\{\alpha_j\}, \{s_j\}} & \sum_i^{\text{images}} \sum_j^{\text{pixels}} |l_i(u_j, v_j) \alpha_j - n(u_j, v_j) \cdot s_j| \\ \text{s.c.} & \alpha_j \geq 1 \end{aligned}$$

Unknowns are “orthogonal”: α_j constant between images, s_j constant between pixels

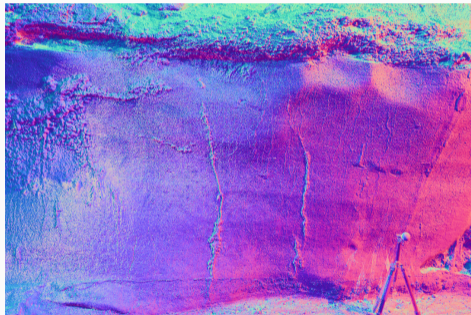
Numerical methods

- Quadratic programming
- Iteratively reweighted least squares

Need for a local estimation



PS with light calibrated by a sphere



PS with light calibrated by the scene

3D digitization of heritage

Calibrated photometric stereo

Self-calibrated photometric stereo

Locally self-calibrated photometric stereo

A complex lighting



“Panneau des chevaux
ponctués”

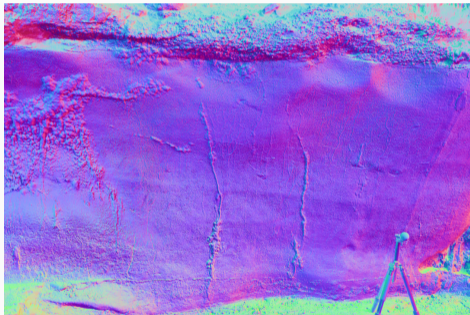


Locally estimated
illumination direction

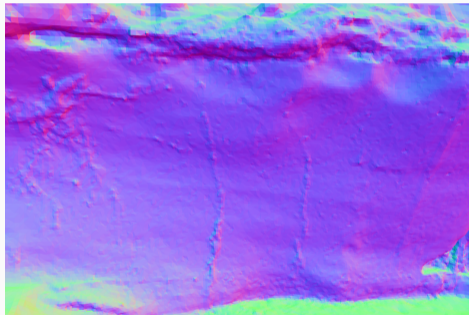


Locally estimated
illumination intensity

Low frequencies fidelity



Locally self-calibrated PS

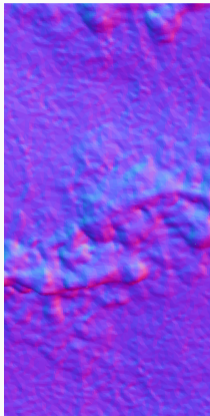


SFM cloud is used as geometric prior

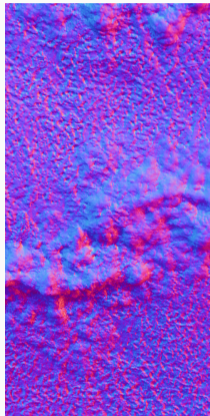
Detail preservation



SFM, used as prior
for calibrated PS



MVS, a classical
multi-view method



Locally self-calibrated PS

Albedo and shading



Influence of shading on color perception



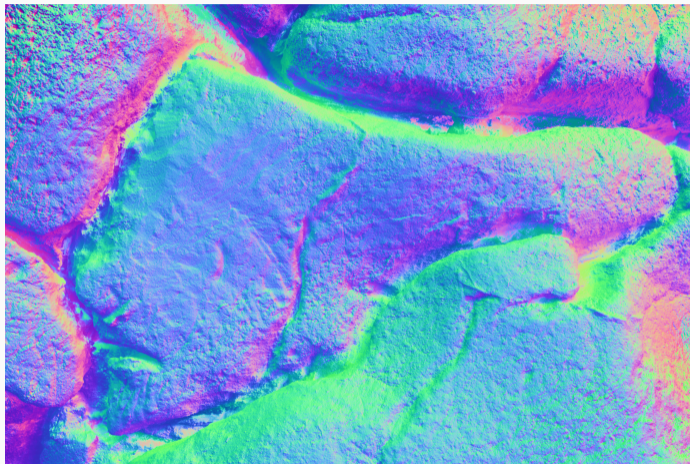
Albedo estimated by locally self-calibrated PS

Case of the Mas d'Azil cave sculpture (1/2)



“Le Masque” (Mas d’Azil, Ariège, France)

Case of the Mas d'Azil cave sculpture (2/2)



Normal field estimated by locally self-calibrated PS

Conclusion

- Bring PS out of the laboratory, at the expense of another picture
- Simplify acquisition protocols

Perspectives

- HDR
- Multi-view