Real-time Photometric Stereo

A. Pevar, L. Verswyvel, S. Georgoulis, N. Cornelis, M. Proesmans, and L. Van Gool

KU Leuven/ESAT/PSI

Photogrammetric Week, Stuttgart, Sept 2015

Context

KULeuven’s Computer Vision group

2D image analysis, segmentation, recognition, 3D reconstruction, surface properties, tracking

On 3D specifically:
❖ Structured light (first one-shot system)
❖ Uncalibrated Structure-from-Motion (first webservice)
❖ Photometric stereo (first transportable system)
Real-time Photometric Stereo

KULeuven’s Computer Vision group

2D image analysis, segmentation, recognition, 3D reconstruction, surface properties, tracking

On 3D specifically:
- Structured light (first one-shot system)
- Uncalibrated Structure-from-Motion (first webservice)
- Photometric stereo (first transportable system)
Real-time Photometric Stereo

Photometric stereo using light domes

- Photometric strengths:
  - Determine high-frequency 3D details
  - Determine surface reflectance

- Minidome: single camera version with 260 LED lights.
The goal of basic PS is to extract the 3D shape (normals) knowing the illumination and local surface albedo and the type of reflectance.

e.g. assuming a Lambertian surface:
\[ I = a ( L \cdot n ) \]

\( n \) can be solved if the surface is illuminated from 3 directions in turn.
Photometric stereography (PS) – the challenge

The goal of basic PS is to extract the 3D shape (normals) knowing the illumination and local surface albedo and the type of reflectance.

e.g. assuming a Lambertian surface:

\[ I = a (L \cdot n) \]

More unknowns can be solved (non-linearly) if there are more measurements (more light sources).

The previous conditions can be relaxed. A solution for the diffuse (Lambertian) component still possible by removing specular outliers among multiple illuminations; this also allows for a more sophisticated reflectance model: diff + spec comp

e.g. Verbiest and Van Gool, Photometric Stereo with Coherent Outlier Handling and Confidence Estimation, IEEE Conf. on Computer Vision and Pattern Recognition ‘08
Photometric stereo (PS) - the challenge

The previous conditions can be relaxed
A solution for the diffuse (Lambertian) component still possible by removing specular outliers among multiple illuminations; this also allows for a more sophisticated reflectance model: diff + spec comp

This is what is implemented in our CPU version of minidome software:
Lambertian added with a specular lobe of variable width

Real-time Photometric Stereo

Robust Photometric stereo

Outcome of the software pipeline, for all surface points:

- Surface normals (unlike PTM)
- Albedos (color): ‘diffuse material color’
- Specular lobes
Real-time Photometric Stereo

Robust Photometric stereo

From these

- 3D reconstruction by normal integration, allowing users to make metric measurements
- real-time shader filtering for study, research and inspection of objects and artefacts.

Example:

Cuneiform tablet with stamp

Input data
Real-time Photometric Stereo

Example:

Cuneiform tablet with stamp

Minidome viewer

British Museum
‘Map of the world’

The oldest cuneiform finding showing a map of Mesopotamia.
Real-time Photometric Stereo

Literature

- Booklets
- Manuscripts
- Stamps
- Seals

Minidome applications

Coins

- Coin collection from museum of Pisa
- Specularity / Reflections
Van Dyck painting: surface reveals history and possibly identity.

Brushstrokes of older painting are visible underneath hat and cape.

Insects: traditionally ‘difficult to scan’

Need for non-destructive measurement techniques.
Minidome applications

Fossils (NHMBerlin)

Minidome applications

Anthropology

- Ivory piece
Minidome applications

Antropology

Kent graffiti plate: copper plate found in Kent (UK), origin was never known, until minidome shaders revealed 15th century Ship graffiti (3 master).

Real-time Photometric Stereo

Operational status:

The new minidome setup is more rugged: 3D printing / silicon mall reproducible and therefore now available @ 11 kEuro
Real-time Photometric Stereo

Operational status:

- Processing speed 2m – 15m, depending on resolution and CPU power.
  E.g. 30 Mpix image sequence (x260), runs > 10 minutes on 8 cores.
- Processing is off-line, as batch job.
- Success of recording (influenced by camera aperture and shutter speed settings) can only be evaluated afterwards.
- GPU implementation offers the possibility for on-line evaluation and real-time processing.
Real-time Photometric Stereo

Operational status:

- Processing speed 2m – 15m, depending on resolution and CPU power. E.g. 30 Mpix image sequence (x260), runs > 10 minutes on 8 cores.
- Processing is off-line, as batch job.
- Success of recording (influenced by camera aperture and shutter speed settings) can only be evaluated afterwards.
- GPU implementation offers the possibility for on-line evaluation and real-time processing. *Diffuse only now*

Real-time Photometric Stereo

GPU implementation:

- Processing of PS is parallel per pixel, based on (at most) 260 observations (LEDs)
- Each pixel is executed by one available thread on the GPU, but each thread deals with multiple pixels
- Careful optimization between thread processing power / memory type: shared, register, cache, global (red is faster but limited) / memory coalescing
Real-time Photometric Stereo

GPU implementation:

- Further optimizations: 260 images call for quite a lot of memory and may not fit on a typical GPU.

- 1) Images are sliced into sections and processed one by one.

- 2) Processing takes advantage of the possibility of transfer concurrency while a previous stored slice is processed.

More information on the GPU implementation found in the Photometric Week 2015 paper

A. Pevar et al.

Real-time photometric stereo
Real-time Photometric Stereo

GPU implementation:

Results:

- Speedup close to factor 1000. Depends on graphics card specs.
- Table shows performance increase on GTX 780ti. On GX980 speedup increases with another factor > 1.5. On TitanX another > 1.5.
  Unit: milliseconds

<table>
<thead>
<tr>
<th>Resolution</th>
<th>CPU</th>
<th>GPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2MP</td>
<td>158*10^3</td>
<td>265</td>
</tr>
<tr>
<td>1.7MP</td>
<td>252*10^3</td>
<td>267</td>
</tr>
<tr>
<td>2.7MP</td>
<td>401*10^3</td>
<td>431</td>
</tr>
<tr>
<td>3MP</td>
<td>445*10^3</td>
<td>480</td>
</tr>
<tr>
<td>6MP</td>
<td>891*10^3</td>
<td>966</td>
</tr>
<tr>
<td>28MP</td>
<td>4185*10^3</td>
<td>5009</td>
</tr>
</tbody>
</table>

Real-time Photometric Stereo

Additional examples (30Mpix)
Future and ongoing work

- CPU:
  - Extracting BRDFs
  - Classifying materials

- GPU:
  - Adding specularities

- hardware:
  - Microdome
  - Multi-spectral

Conclusions

- Robust Photometric stereo algorithm on GPU
- Allows for live processing and visual feedback during recording
- Future work on more complex material representation such as BRDFs (also see S. Georgoulis, M. Proesmans, and L. Van Gool, *A Gaussian Process Latent Variable Model for BRDF Inference*, ICCV, 2015)
Thank you!