Projector Systems to Control the Material Perception of an Object

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1. The appearance of an object or scene is determined by factors like the material, the lights, the geometry, the position of the observer, and the surroundings. **This project aims to simulate changes in the scene's appearance by actively manipulating the lighting using a projector-camera setup.** This can be used for projection mapping applications, like art and advertisement.

2. Setup

- Projector-camera setup
- Camera is off-axis
  - Can be used as a stereoscopic setup

Now, a projection must be generated to make the scene look like a desired scene.

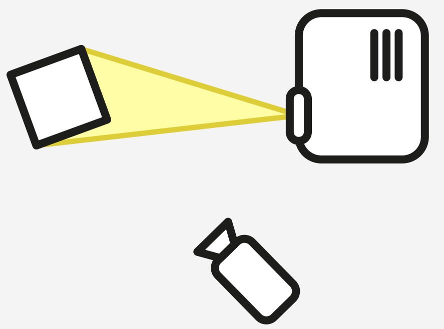

Fig. 1. Projector-Camera setup.

3. Naive Prototype

- Provide the desired scene virtually
- This is projection-mapped onto some real-life geometry
- Downside: The geometry needs to be known

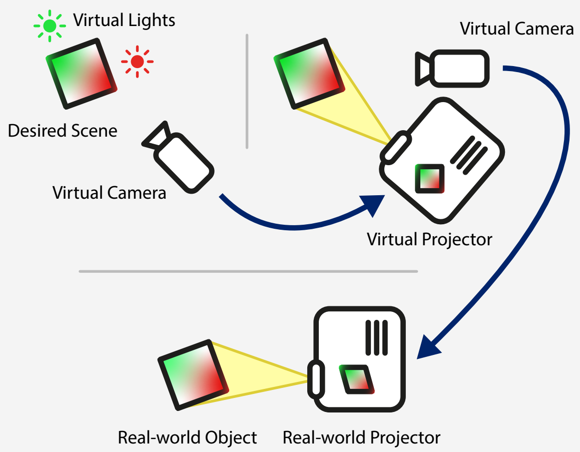

Fig. 2. Pipeline of the Naive Prototype.

4. Iterative Prototype

- Provide the desired view
- Projection is generated by minimizing the difference between the observed view and the desired view
- Geometry can be unknown

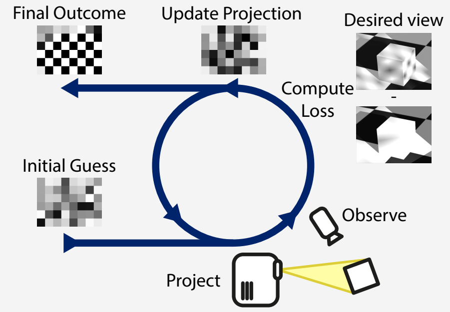

Fig. 3. Pipeline of the Iterative prototype.

5. Calibration

- Measure every projector's pixel influence
- Project-observe step is replaced by a matrix multiplication, speeding it up.

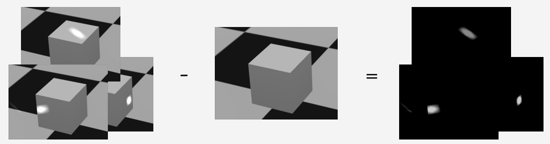

Fig. 4. The calibration step for 3 of the projector's pixels. For every pixel in the projector, a picture is taken. The picture where all projector pixels are off is subtracted from these pictures. The results are stored in the calibration matrix.

6. Function to be Minimized

To make the observed view as much like the desired view, the following function should be minimized:

$$O(P) = \frac{1}{n}\sum_{i=1}^{n}((P \cdot A + B)_i - D_i)^2$$

Eq. 1. This calculates the MSE per pixel between the desired view D, and the projection P multiplied by the calibration matrix A with the all-pixels-off calibration B added.

7. Gradient Prototype

- Gradient of Equation 1 can be calculated
- Providing the gradient to the optimizer speeds it up drastically

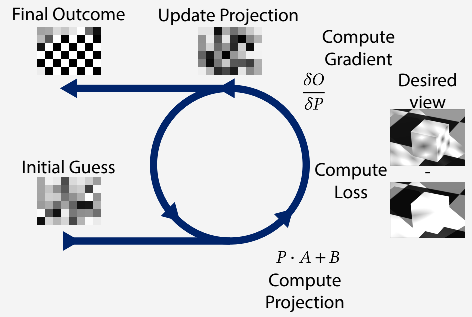

Fig. 5. Pipeline of the gradient prototype.

8. Results

- Real-world projector and camera
- 64 × 36 px projector
- 640 × 480 px camera
- 69 iterations
- 22.9 seconds

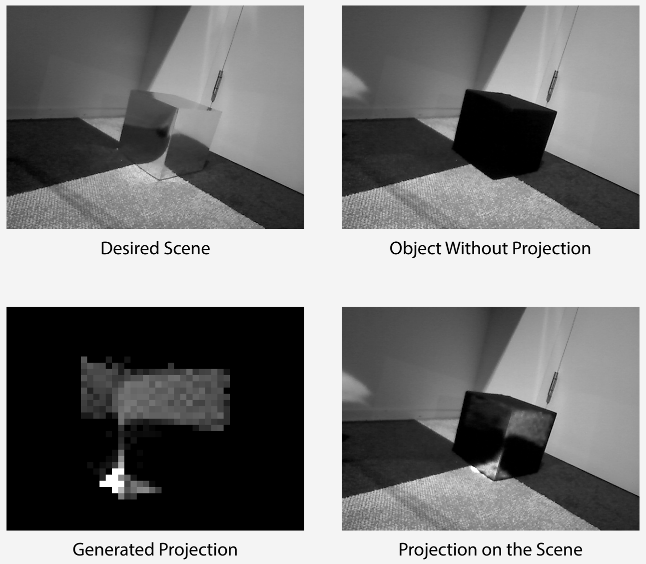

Fig. 6. Result on a real-world object.

9. Discussion

- Good initial guess speeds up the optimization
  - When using a video, using the result of the previous frame as initial guess speeds up the minimizing with a factor of 1.8
- Calibration takes long and is big
  - Can be improved by using smarter patterns like Graycode [1]
  - Can be compressed to 0.14%

Tab. 1. Time and space forcalibration of different sizes. Grey results are linearly extrapolated from the results with a lower projector resolution and the same camera resolution. Note the changing units.

	Camera Resolution	
Projector Resolution	640 × 360 px	1920 × 1080 px
40 × 30 px	276 MB, 373 s	2.5 GB, 365 s
1920 × 1080 px	476 GB, 135 h	4.3 TB. 173 h

- Projecting on a surface brighter than the desired scene does not work
  - The prototype only knows how to make objects brighter
  - Our eyes adjust when everything is brighter, so it could make parts appear darker.
  - Projector and camera can be adjusted to make the black and white slightly under- and overexpose the camera [2]
  - A tone-mapping function could be added to the loss function [3]

10. References

[1] Lanman, D. and G. Taubin (2009). Build your own 3D scanner: optical triangulation for beginners. ACM SIGGRAPH ASIA 2009 Courses. Yokohama, Japan, Association for Computing Machinery: Article 2.

[2] Huang, B. and H. Ling (2019). End-To-End Projector Photometric Compensation. 2019 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR).

[3] Anrys, F. a. D., Philip and Willems, Yves D (2004). Image-based lighting design.

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