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Medical Imaging and Computer-Aided Diagnosis

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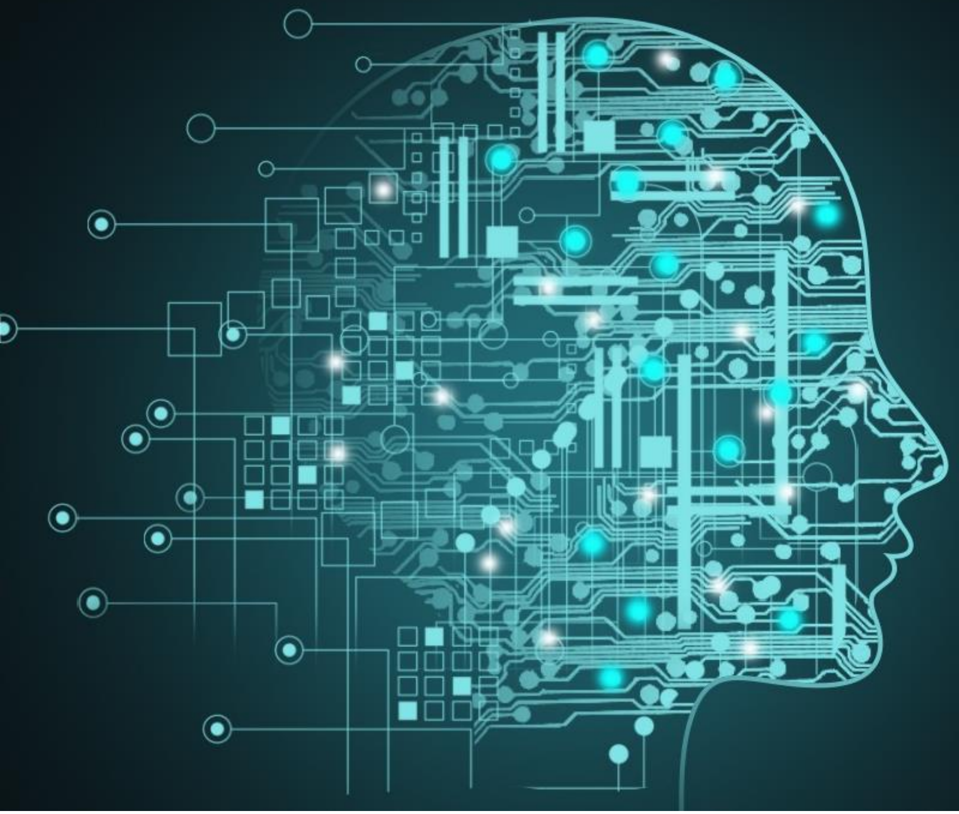
CG VR



371

Optimizing the Illumination of a Surgical Site in New Autonomous Module-based Surgical Lighting Systems

Andre Mühlenbrock, René Weller and Gabriel Zachmann

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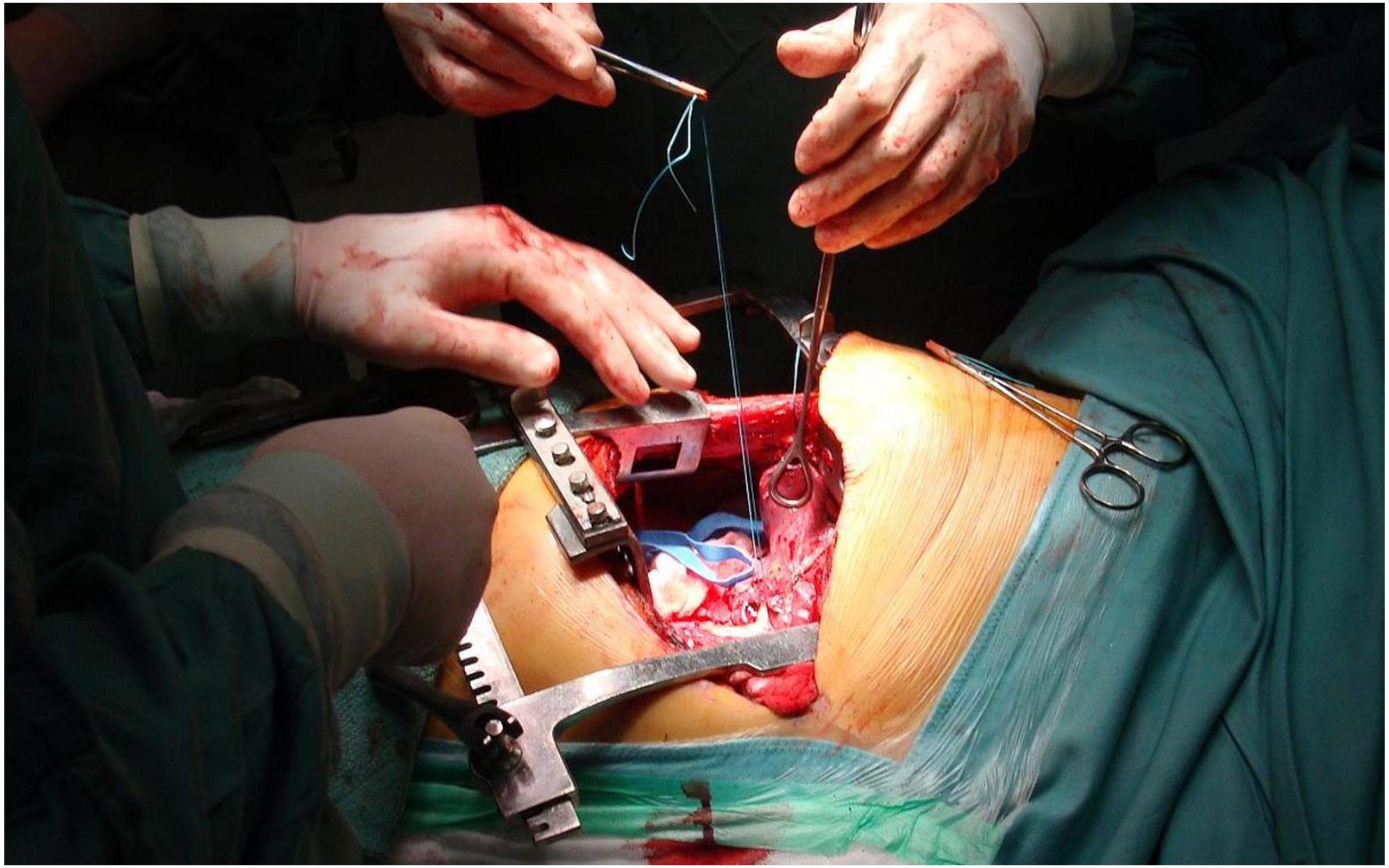
Motivation



Removal of a lung tumor (Wikimedia.org, Wojciech Filipiak)

Motivation

- Drawbacks of current OR lighting methods:
  - **OR lights** cast shadows and need frequent readjustment
  - **Headlights** are strenuous to wear and require the surgeon to assume a certain head pose.
  - **Lighted retractors** often provide non optimal lighting, causes issues of sterility and risk of burning.

Wikimedia.org, Mazda Farshad

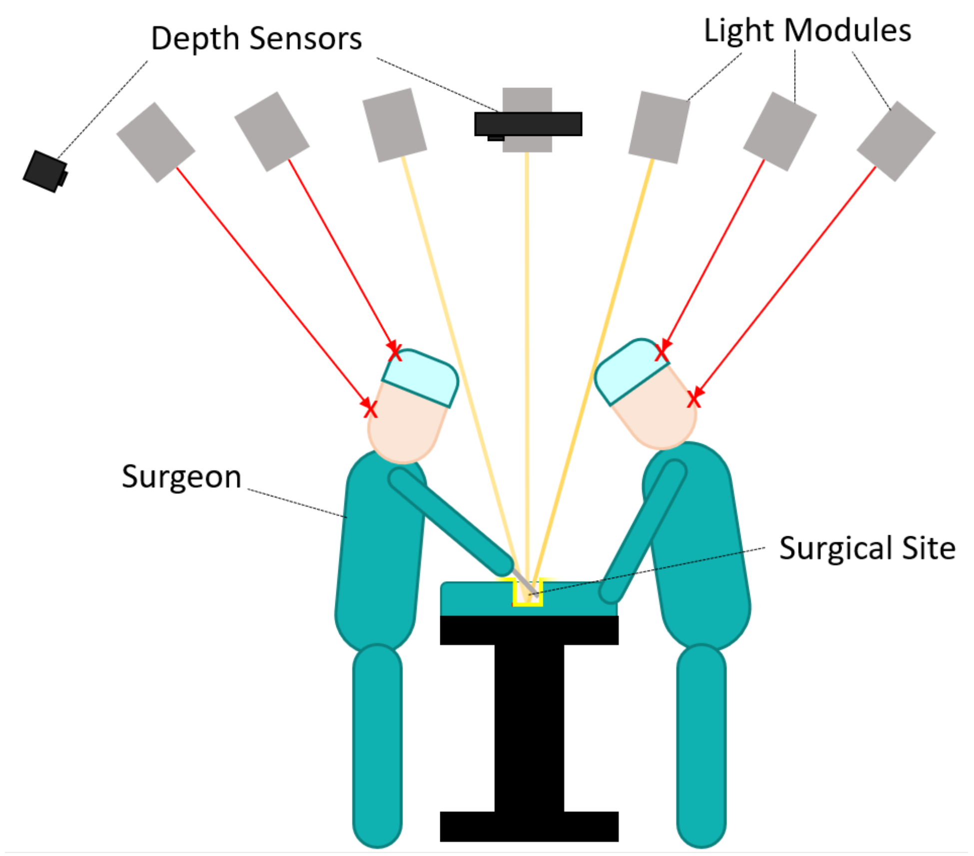
Goal

- Constant illumination of the site
    - Shadow-free
- No distraction of the surgeon
    - No interruptions due to light adjustments
    - No collisions with lights (e.g. OR lights)
    - No restriction of head movement (e.g. headlights)
- Safe, affordable and feasible

Solution

- An autonomous module-based lighting system

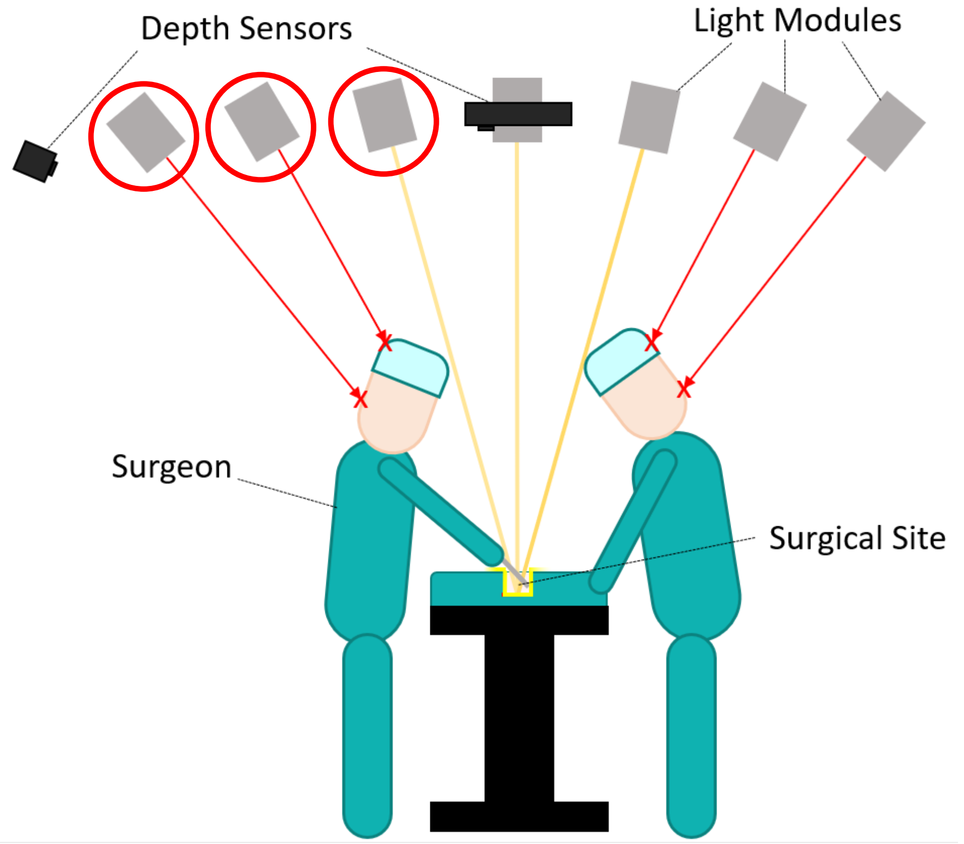
Side view



Solution

- An autonomous module-based lighting system
  - Use many **light modules** simultaneously.
    - Controllable rotation and intensity

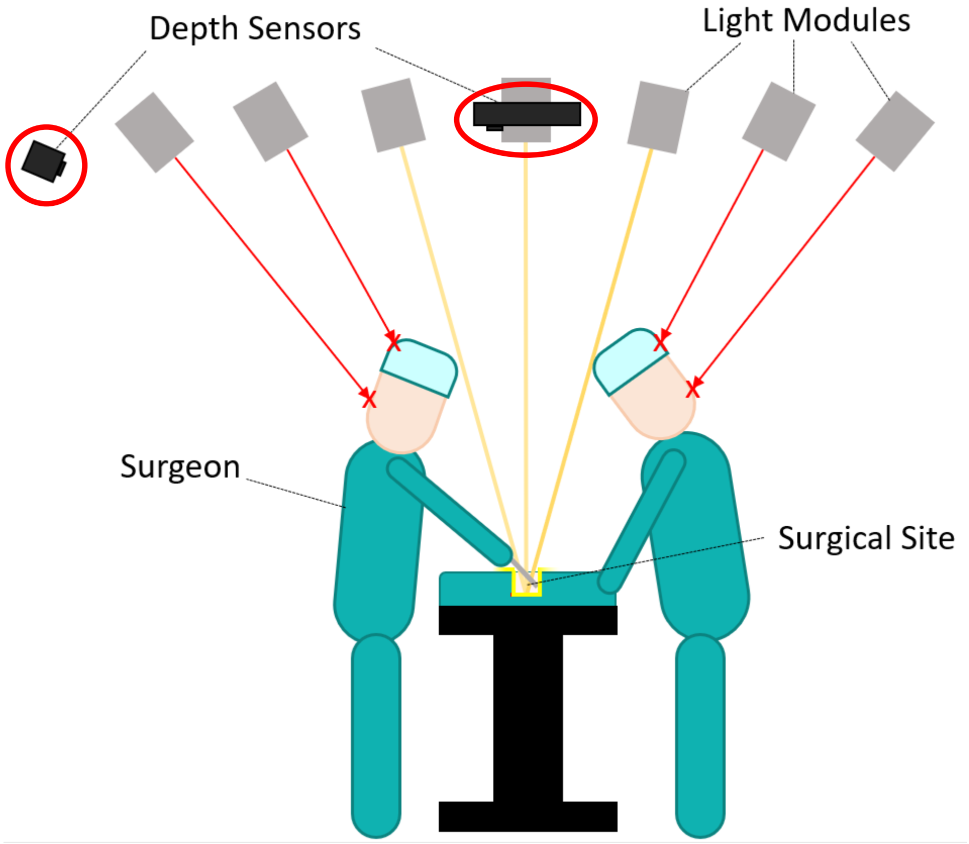
Side view



Solution

- An autonomous module-based lighting system
  - Use many **light modules** simultaneously
    - Controllable rotation and intensity
  - Detect surgical staff using **depth sensors**

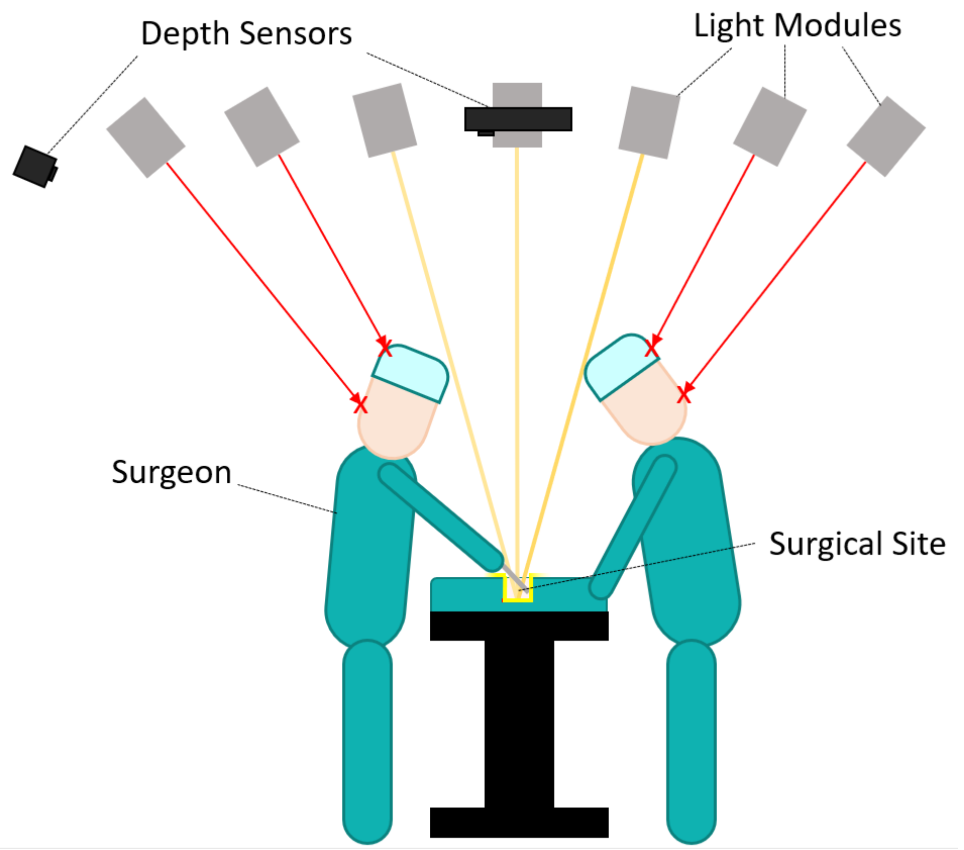
Side view



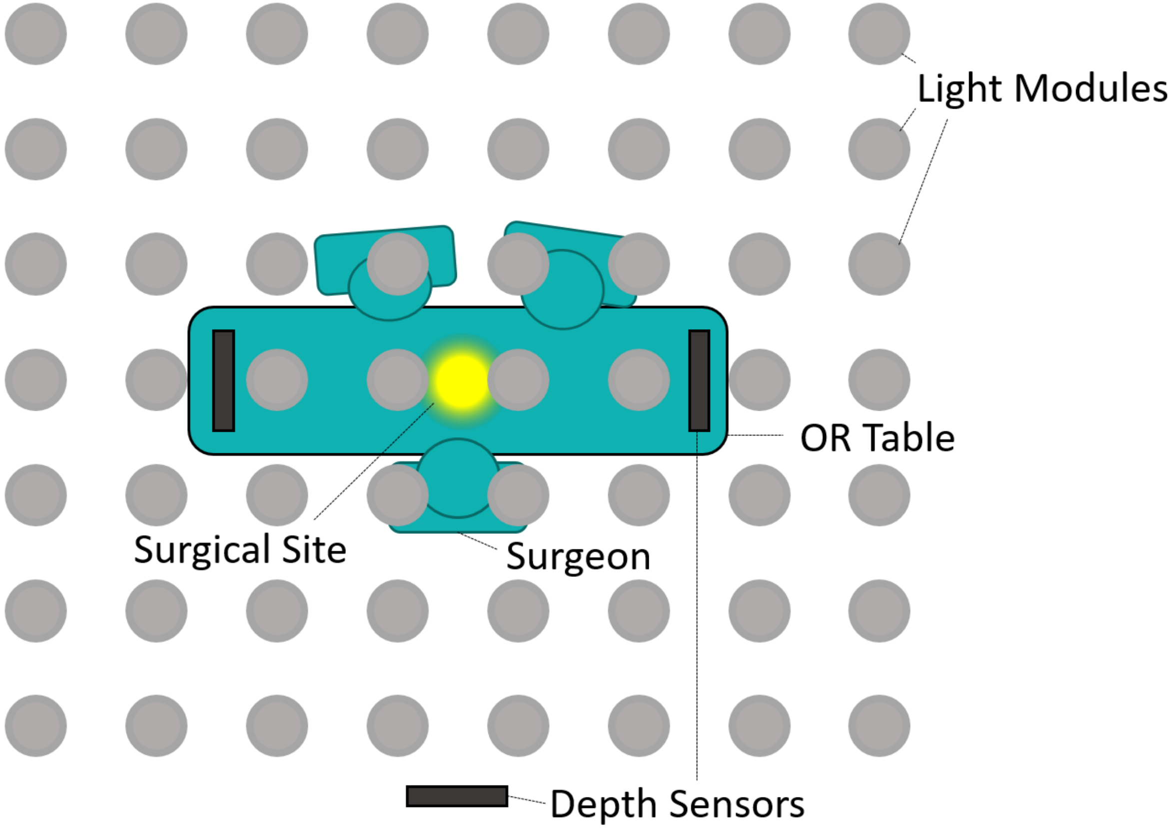
Solution

- An autonomous module-based lighting system
  - Use many **light modules** simultaneously.
    - Controllable rotation and intensity
  - Detect surgical staff using **depth sensors**.
  - **Optimize light module intensities** to obtain a constant shadow-free illumination at the site.

Side view



Top Down View



Challenges

- How to detect which light modules are blocked?
- How to control the intensity of light modules?

- **Optimization Goals:**
  - **Constant bright** illumination (also for deep wounds)
  - Surgeons should **not be distracted** by light changes
  - **Real-time**

Optimization Pipeline

Input: Depth sensors provide **depth images**

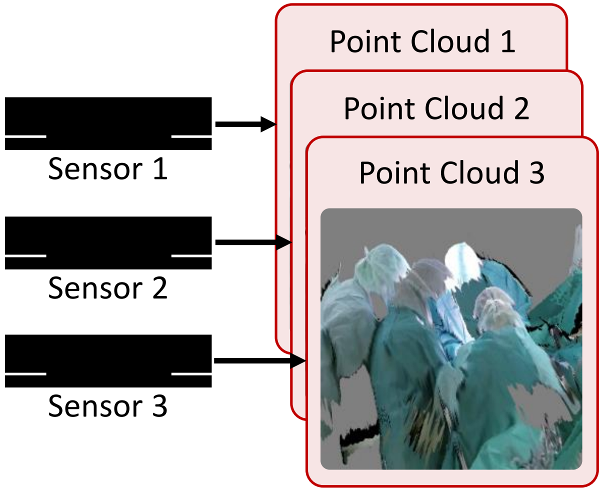
Sensor 1

Sensor 2

Sensor 3

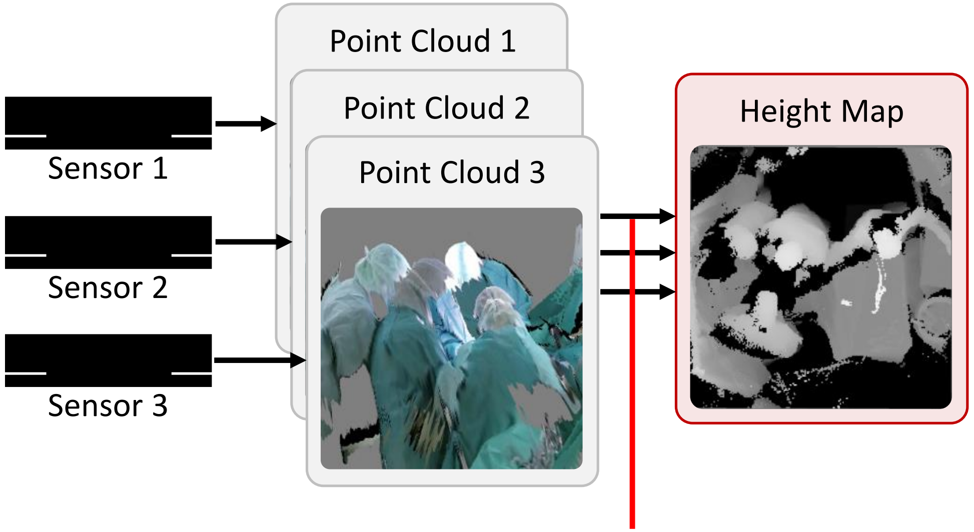
Optimization Pipeline

Step 1: Transform **depth images** to **point clouds**



Optimization Pipeline

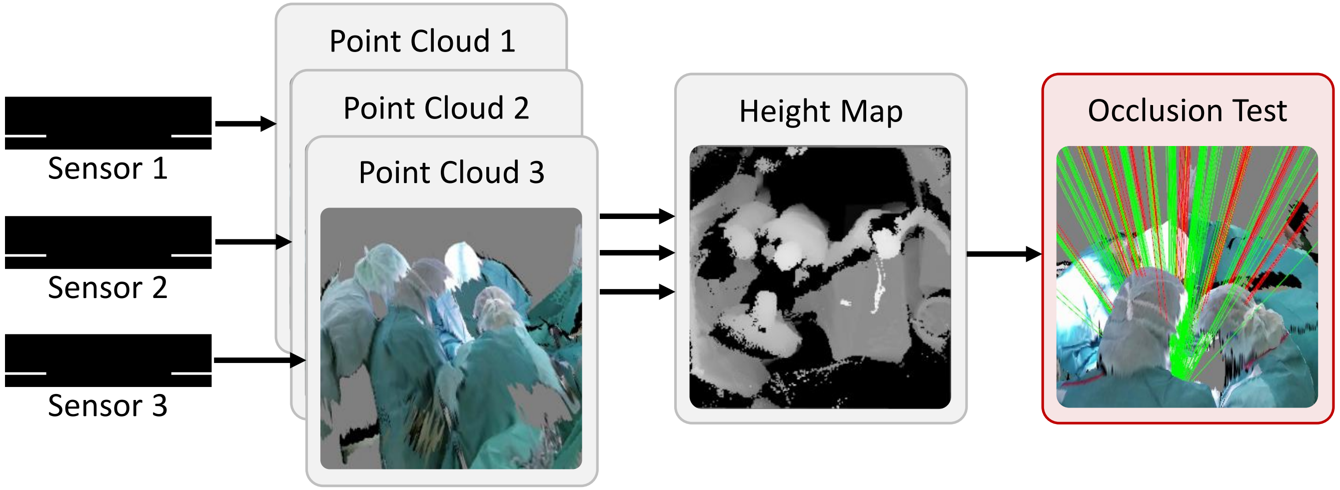
Step 2: Project **point clouds** onto a common **height map**



Using the world registration
of each sensor

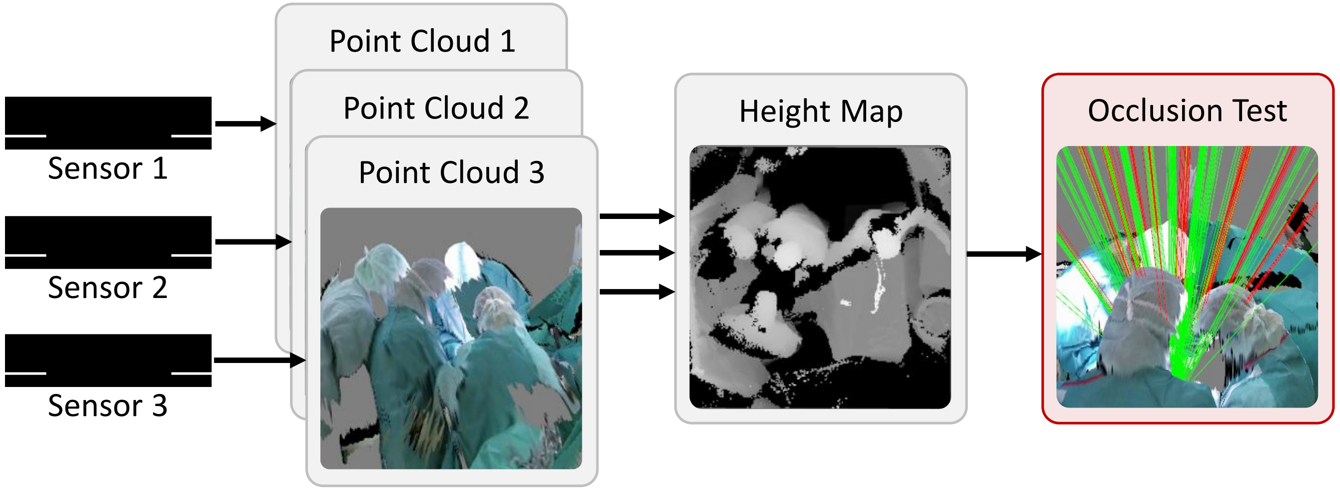
Optimization Pipeline

Step 3: Perform (multiple) **occlusion tests** for every light module using the **height map**

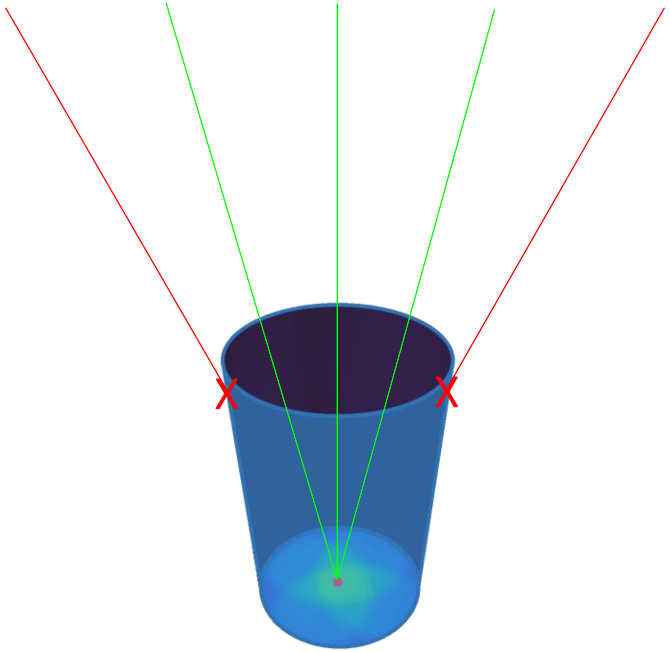


Optimization Pipeline

Step 3: Perform (multiple) **occlusion tests** for every light module using the **height map** and a **virtual 3d site**



Test also against a virtual tube for depth illumination:



Optimization Pipeline

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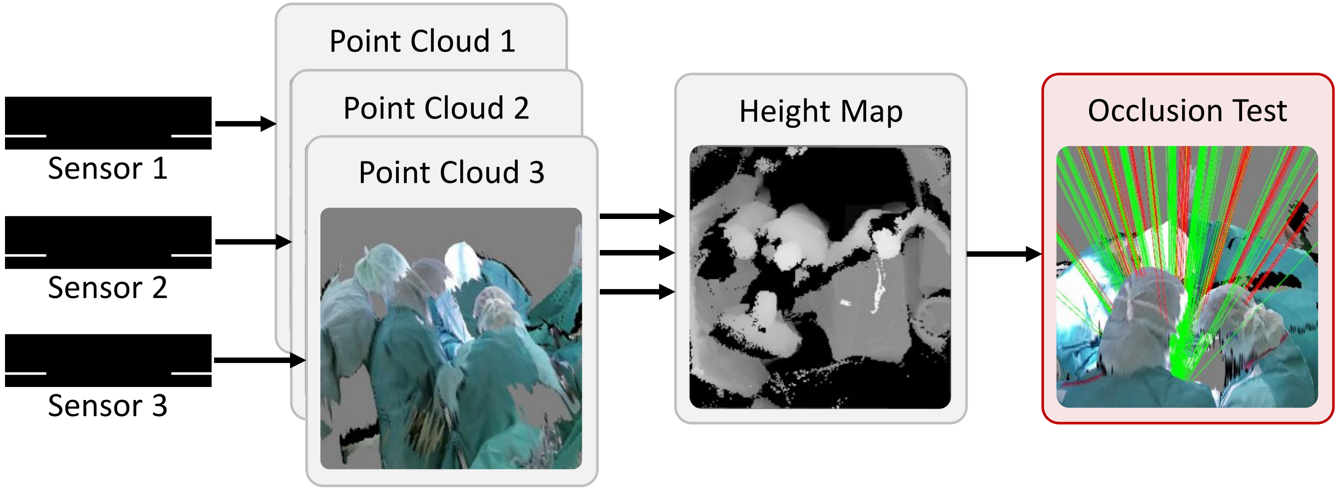
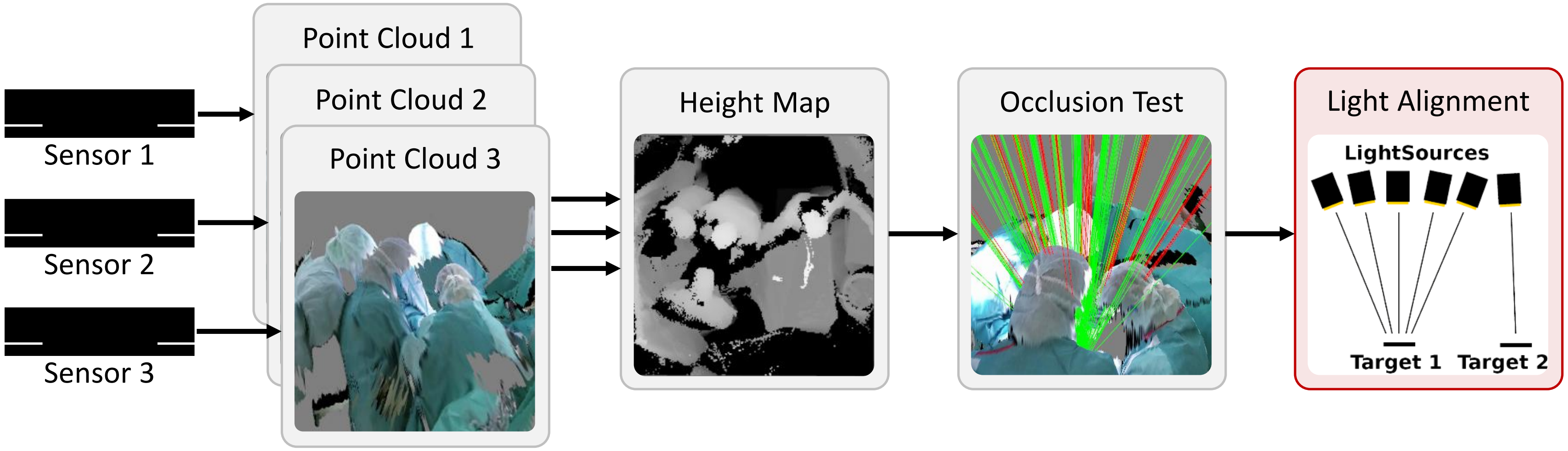


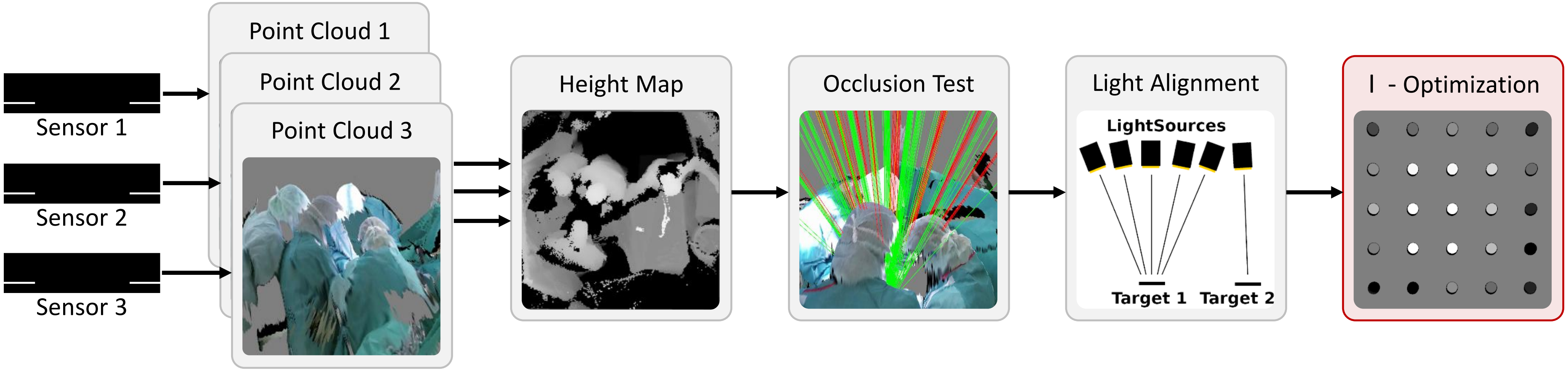
Optimization Pipeline

Step 4: Assign and rotate all light modules to a target **(light alignment).**



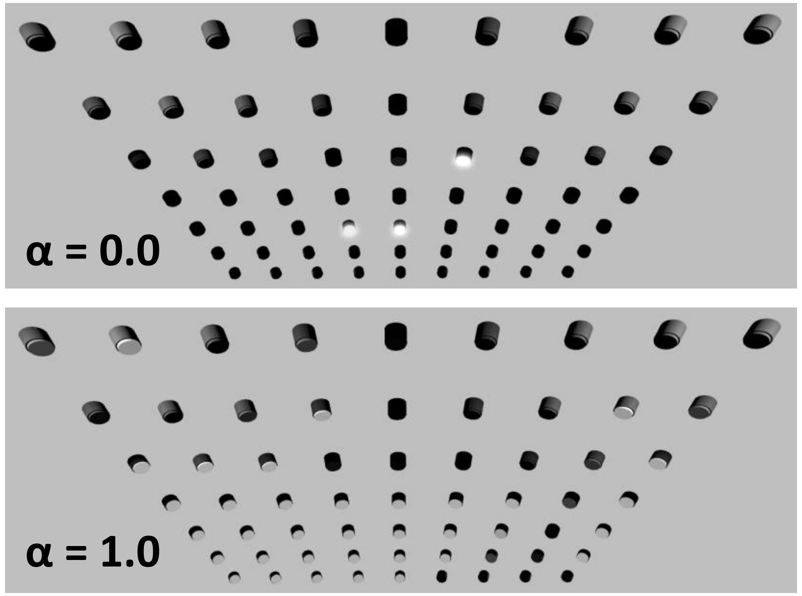
Optimization Pipeline

Step 5: Determine an **optimal intensity** for every **light module**.



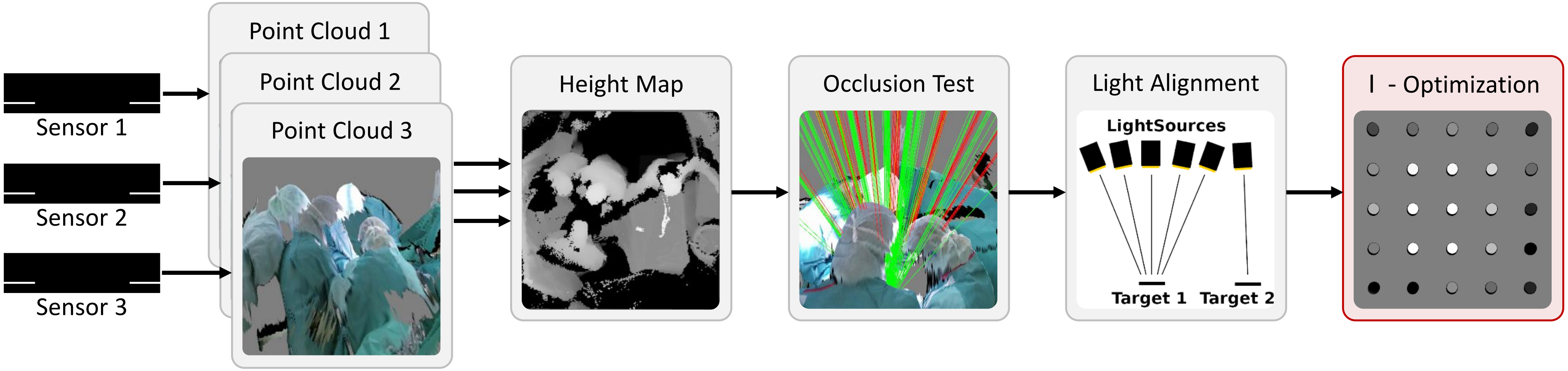
I – Optimization

- **Our implementation:**
  - Allows to smoothly fade between:
    - Minimization of number of lights (**α**=0.0)
    - Maximization of number of lights (**α**=1.0)
  - Allows different criteria, e.g.:
    - Prefer **most perpendicular light** to surgical site
    - Prefer light modules whose light was **unblocked for a longer period of time**.



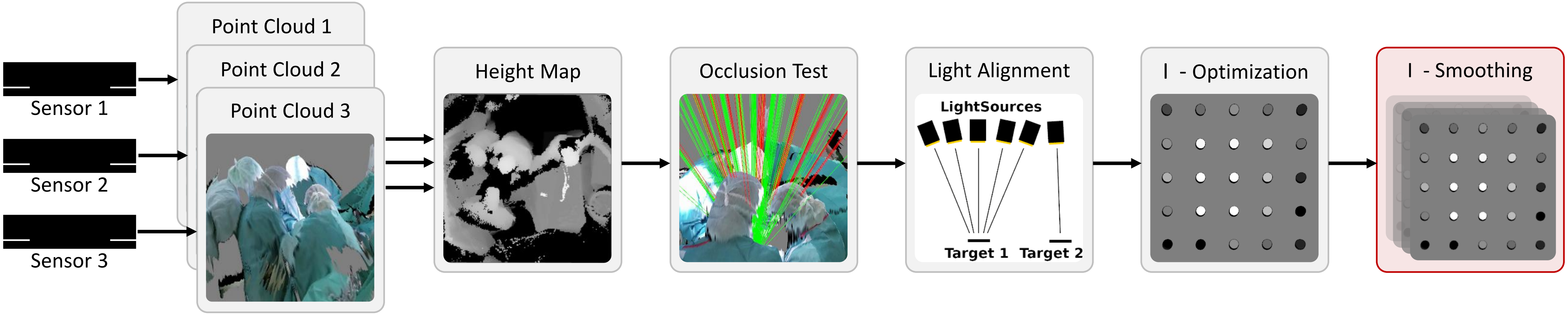
Optimization Pipeline

Step 5: Determine an **optimal intensity** for every **light module.**



Optimization Pipeline

Step 6: Smooth intensities over time to not distract the surgeons.



Optimization Pipeline

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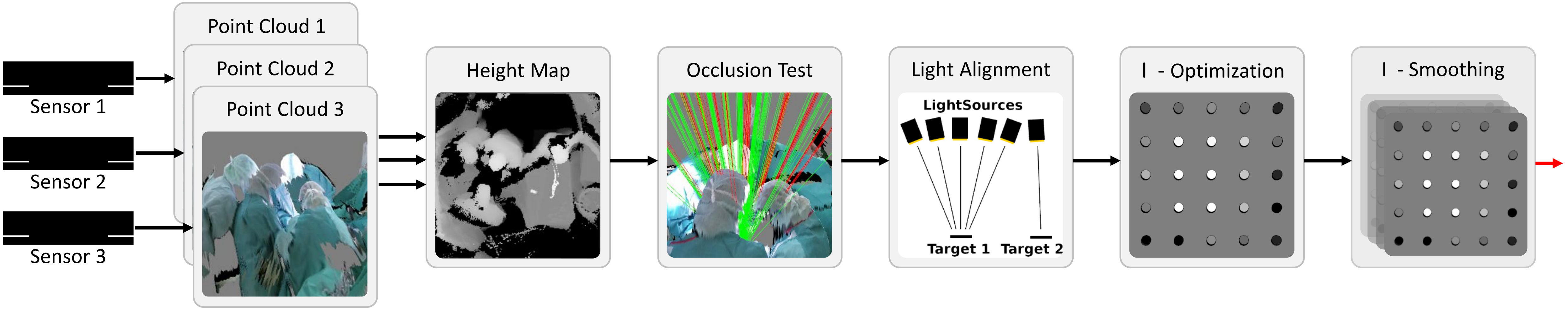
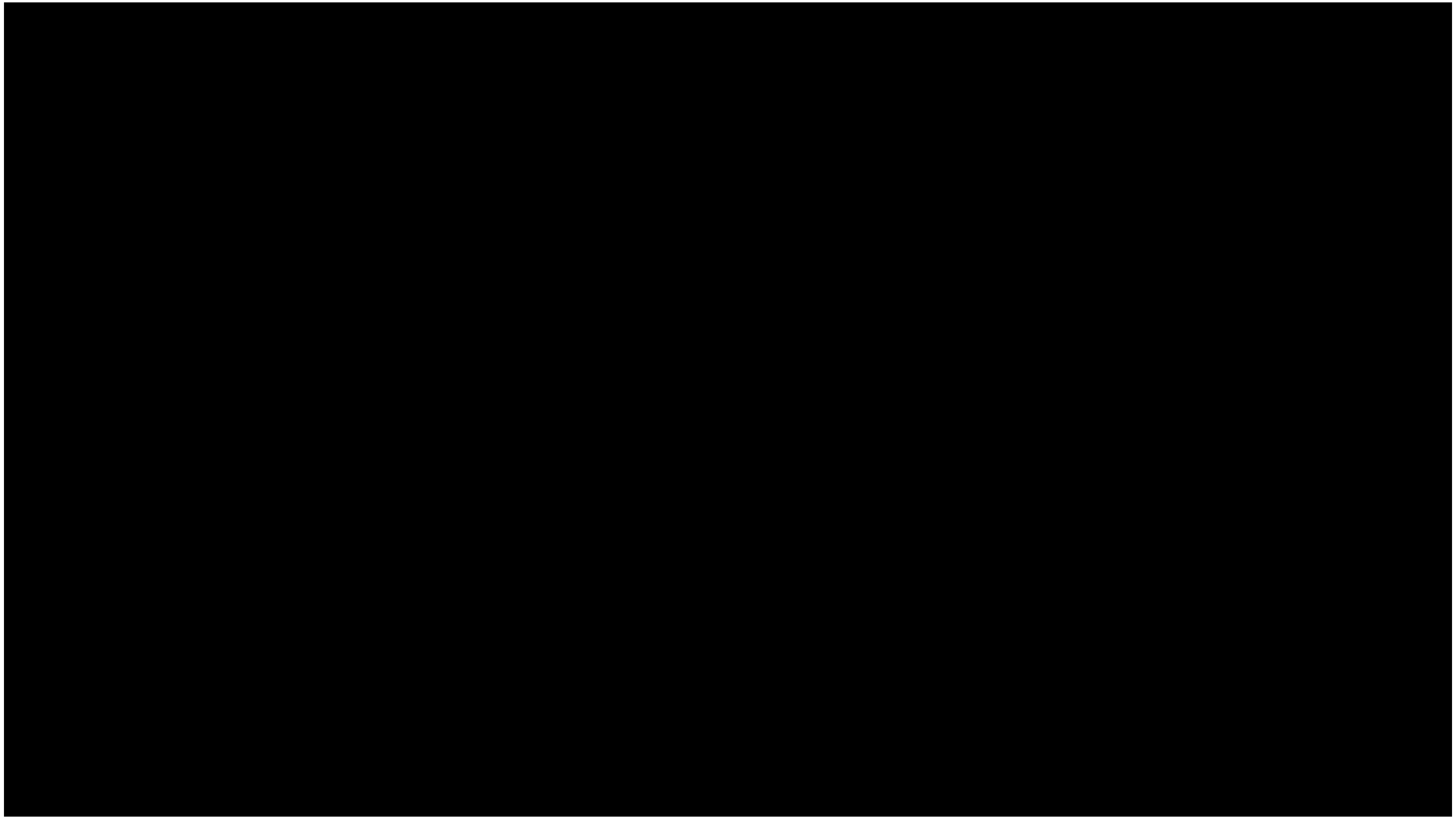


Evaluation Setup

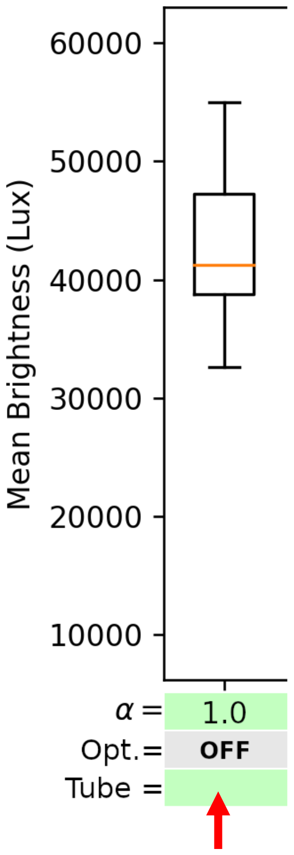


Evaluation Setup

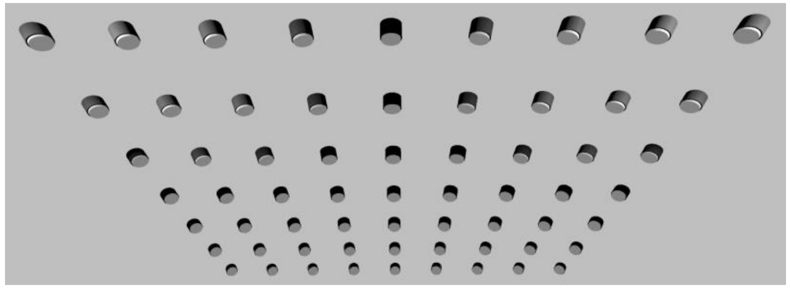
- **Key data:**
  - **56 light modules** (7 x 8 grid)
  - Up to **50 klx** at **1.9m** per light module
  - **5 x 5** lux sensors in the virtual site (area of 5cm x 5cm)
  - **80 klx** target brightness at the site center

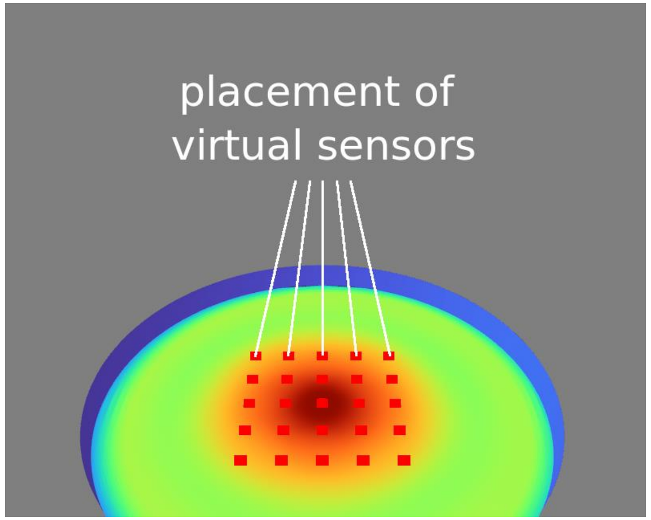
Results

Brightness averaged over time and sensor (n = 9 surgery)



No optimization, all lights equally bright.





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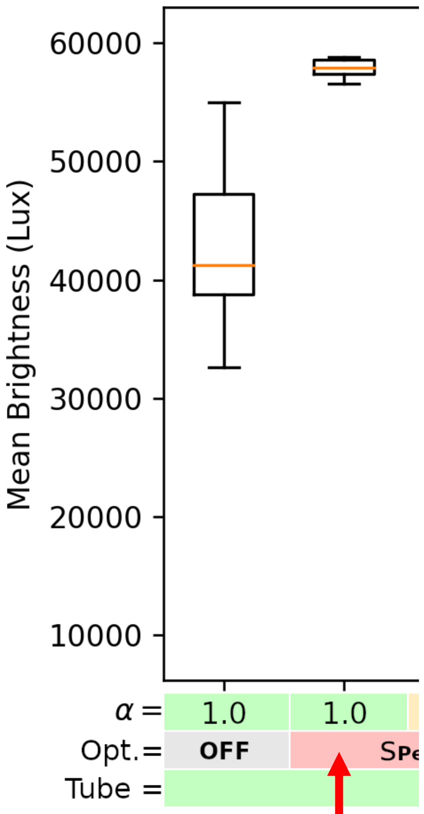
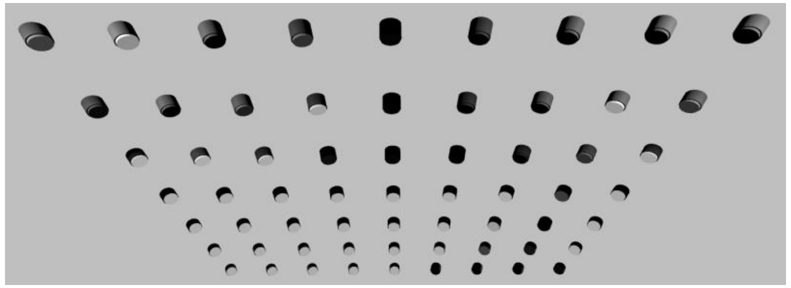
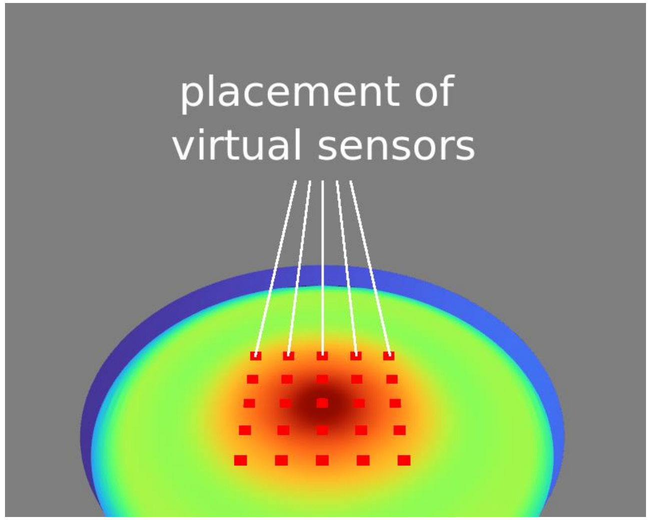


Using as **many** lights as possible
(with optimization)





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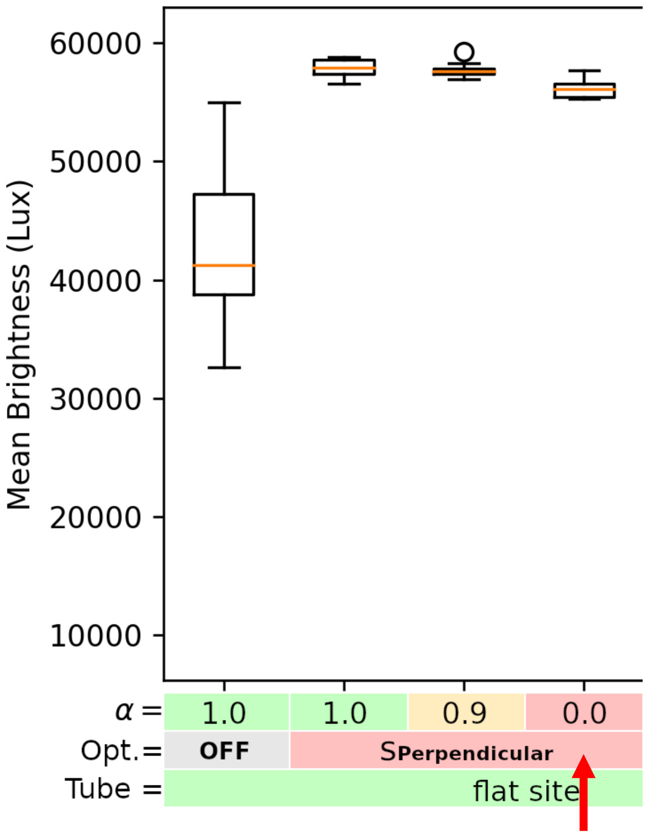
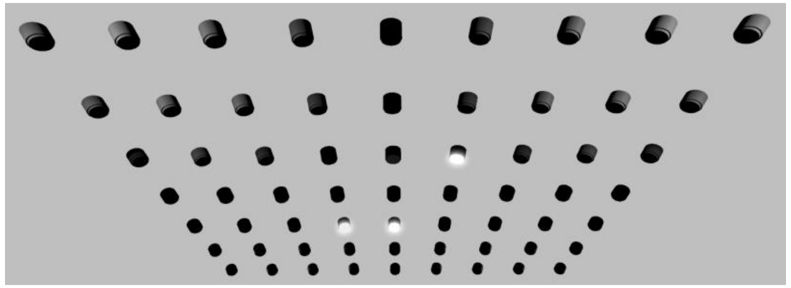
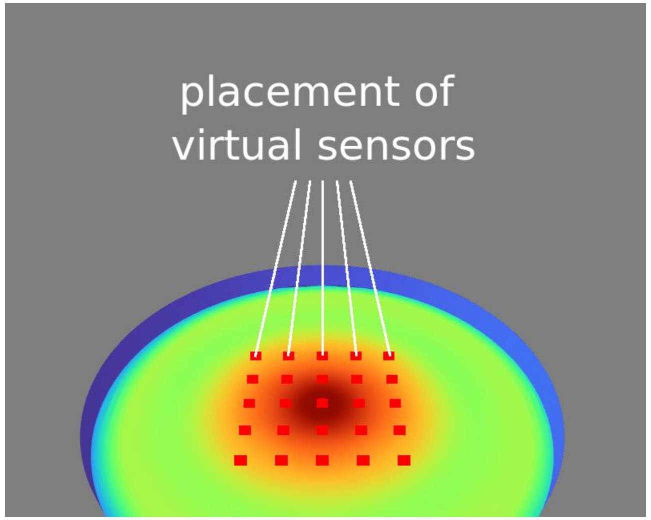


Using as **few** lights as possible
(with optimization)





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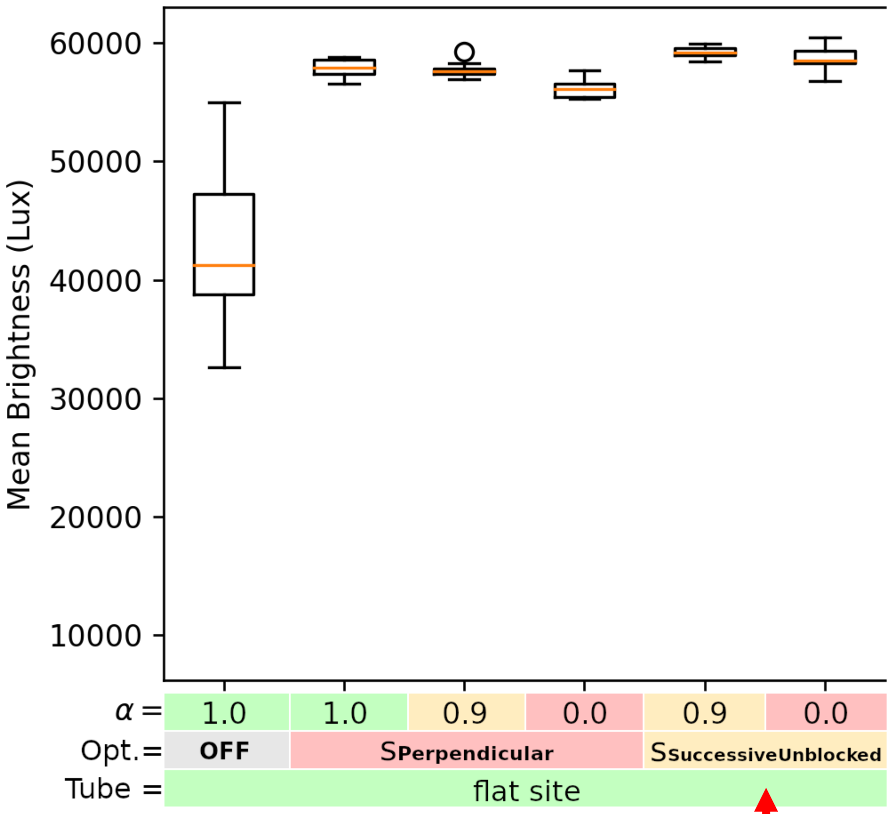
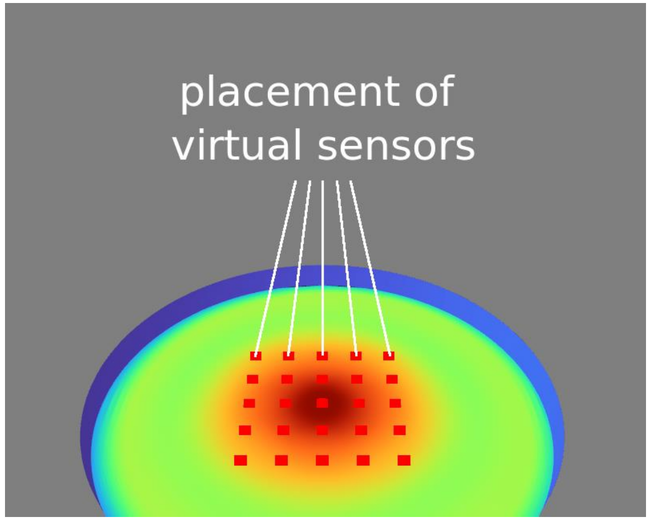


Other criteria in I-Optimization
(see paper)



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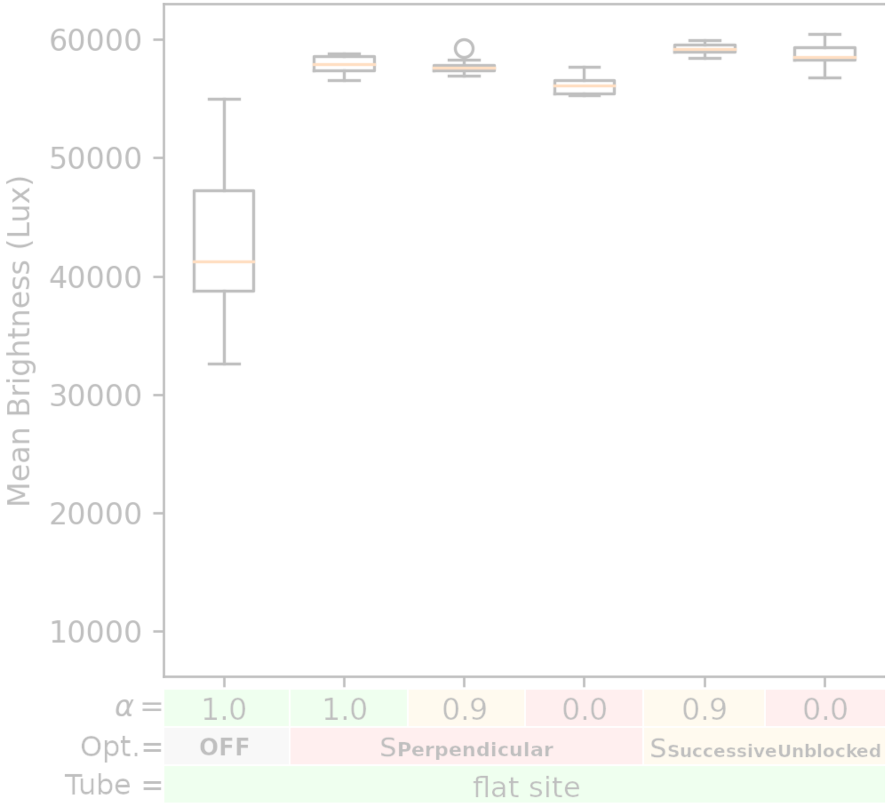

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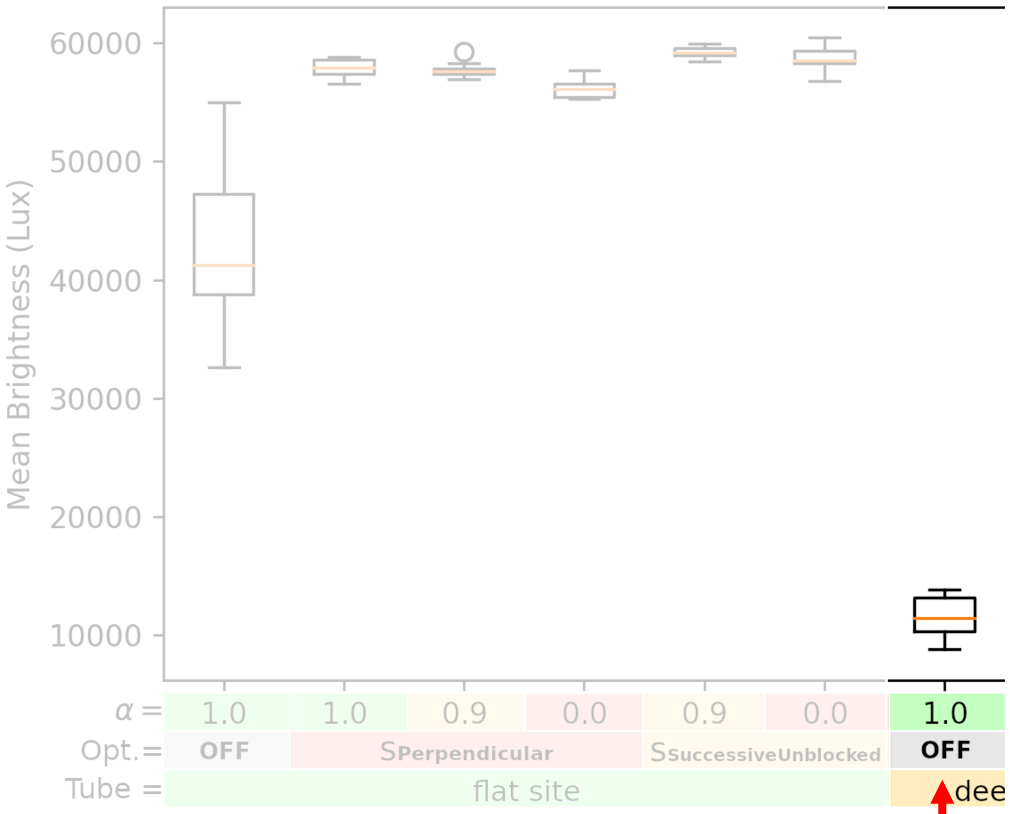
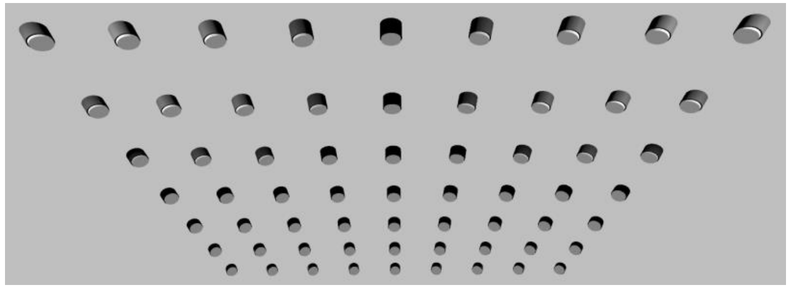
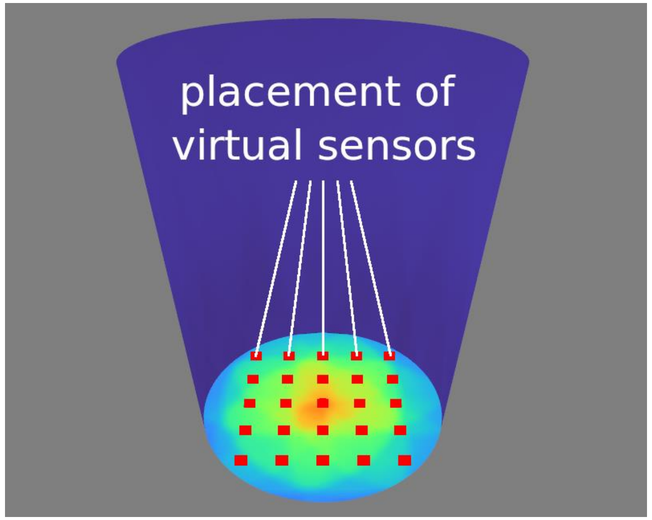


No optimization, all lights equally on.

Using a deep site





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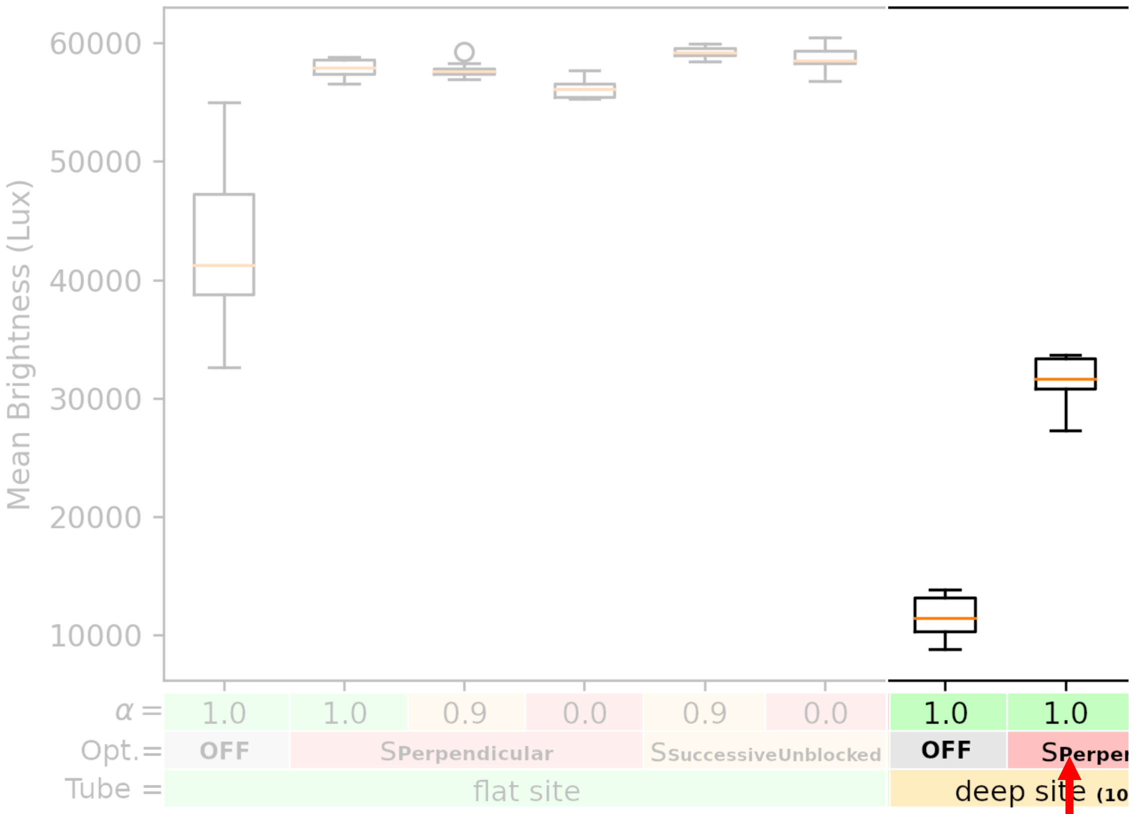

Using as **many** lights as possible
(with optimization)

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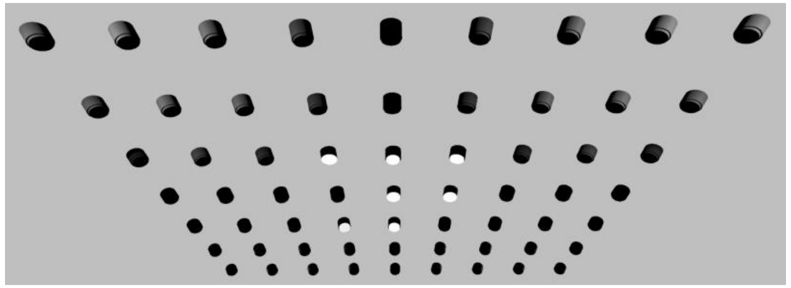

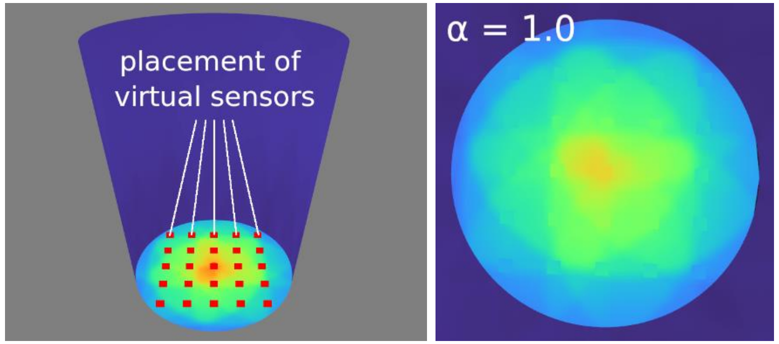

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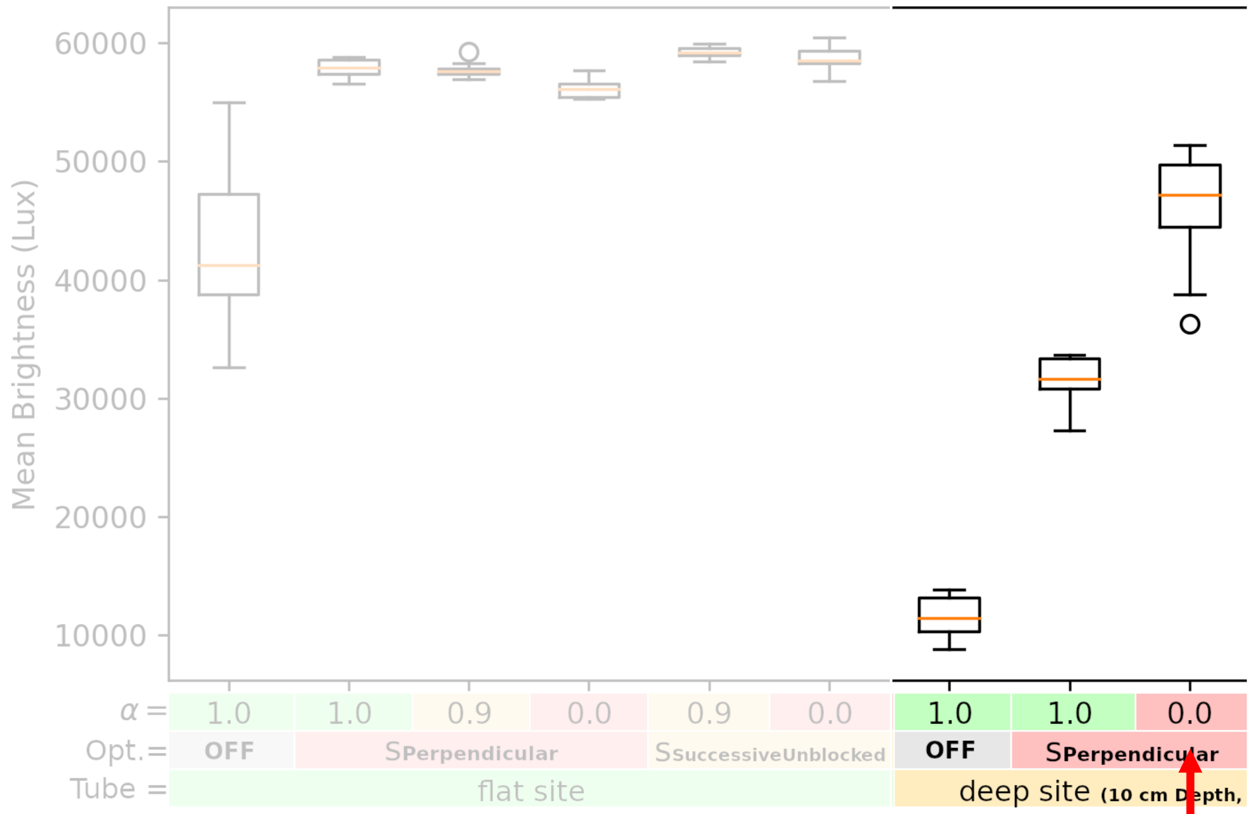

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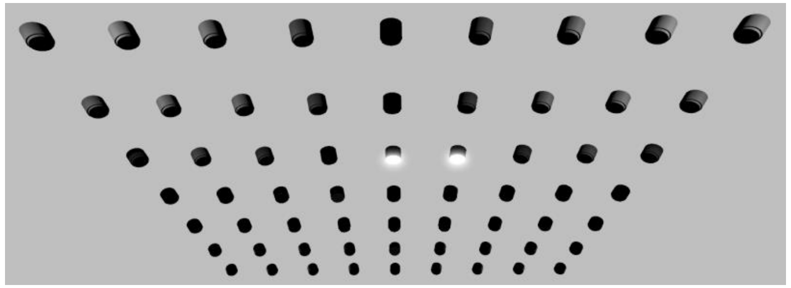

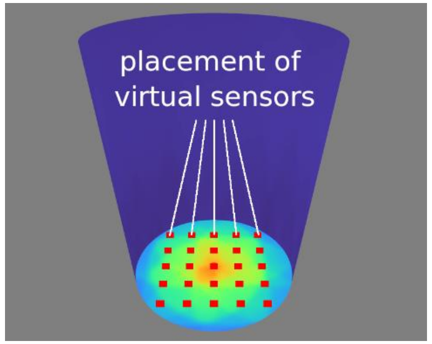

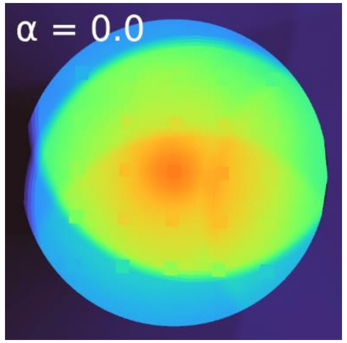

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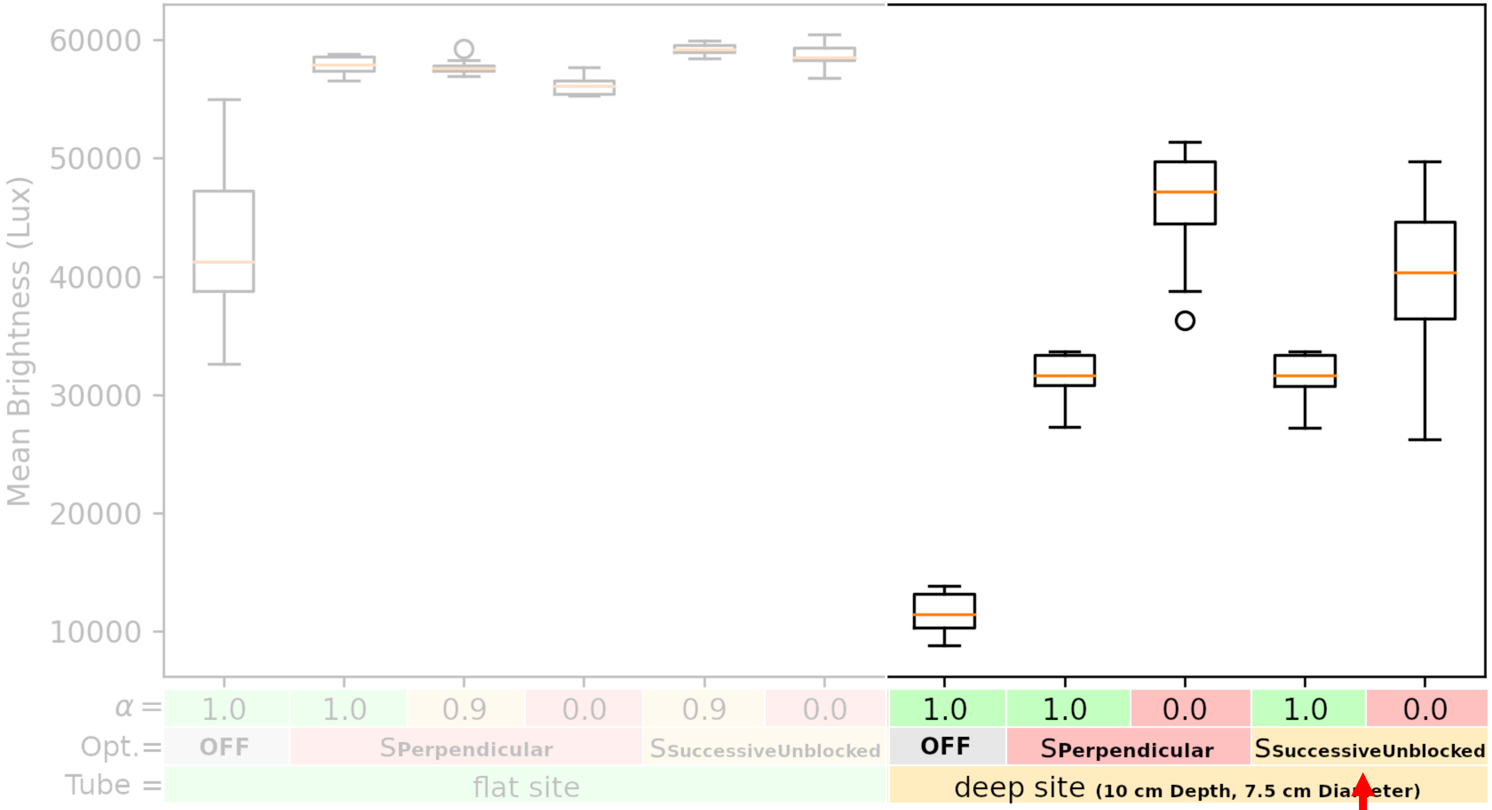
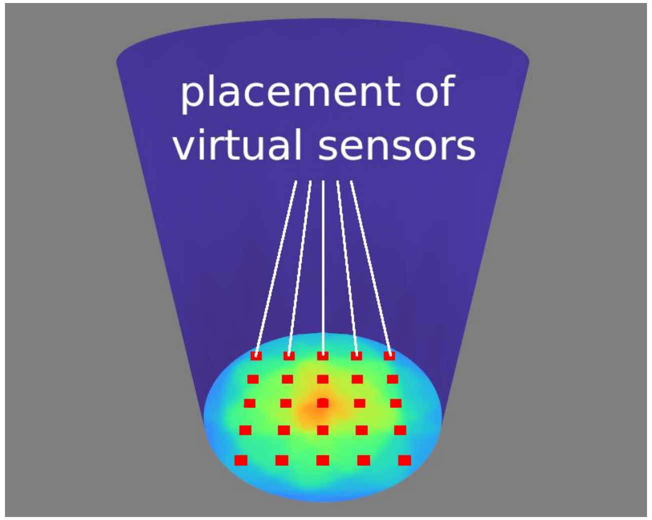
Brightness averaged over time and sensor (n = 9 surgery)



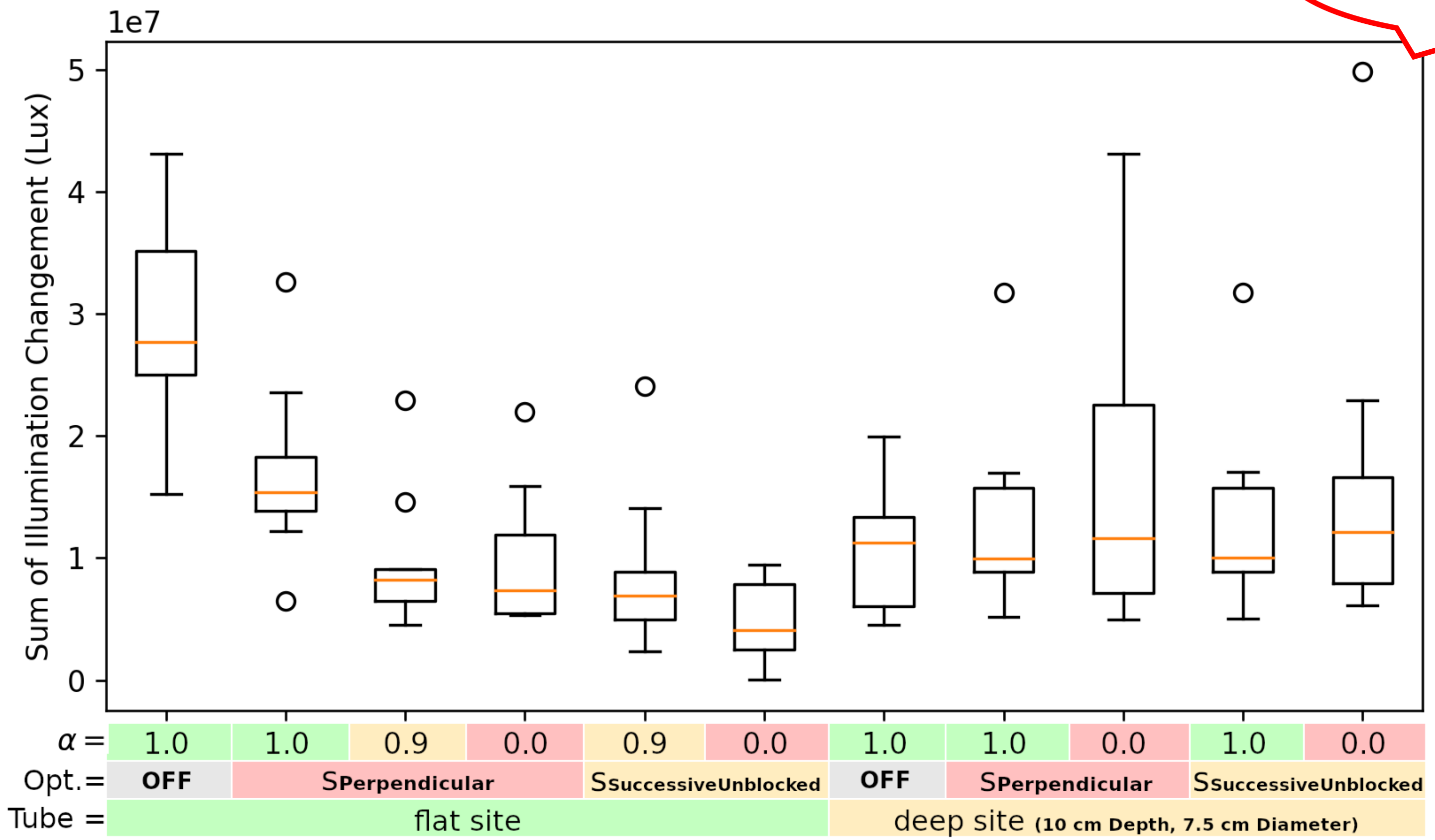


Other criteria in I-Optimization
(see paper)

Results

Sum of brightness changes (n = 9 surgery)

See paper



Conclusion

- A new autonomous module-based lighting system

- Optimization pipeline for controlling light modules
  - **Near to optimum** illumination in case of **flat sites**.
  - **Significant improvement** when illuminating **deep sites**.
  - **Realtime** (≈ 50Hz, three kinects, 56 light modules, single consumer pc)

Outlook: Actual Prototype

Thank you for your attention!

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