Optimizing the Arrangement of Fixed Light Modules in New Autonomous Surgical Lighting Systems

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INTRODUCTION

- **Background:** We are developing a new autonomous lighting system consisting of many fixed light modules placed at the ceiling to illuminate a surgical site.
- **Observation:** Some light modules contribute less to the illumination of the site because of their position (e.g., when they are placed behind the surgeon).
- **Objective:** Find ideal light module positions which ensure best illumination of the site in all surgery situations.

Idea: Capture point cloud recordings of real surgeries and optimize the light positions on these recordings.

METHODS

We used **three depth sensors** to record **nine open abdominal surgeries** (see Fig. 1). Using ray tracing, we can calculate whether the light from a light module will pass through or be blocked on its way to the surgical site (see Fig. 2).

Figure 1. Depth sensors mounted on the ceiling of an operating room at the PIUS Hospital, Oldenburg, Germany.

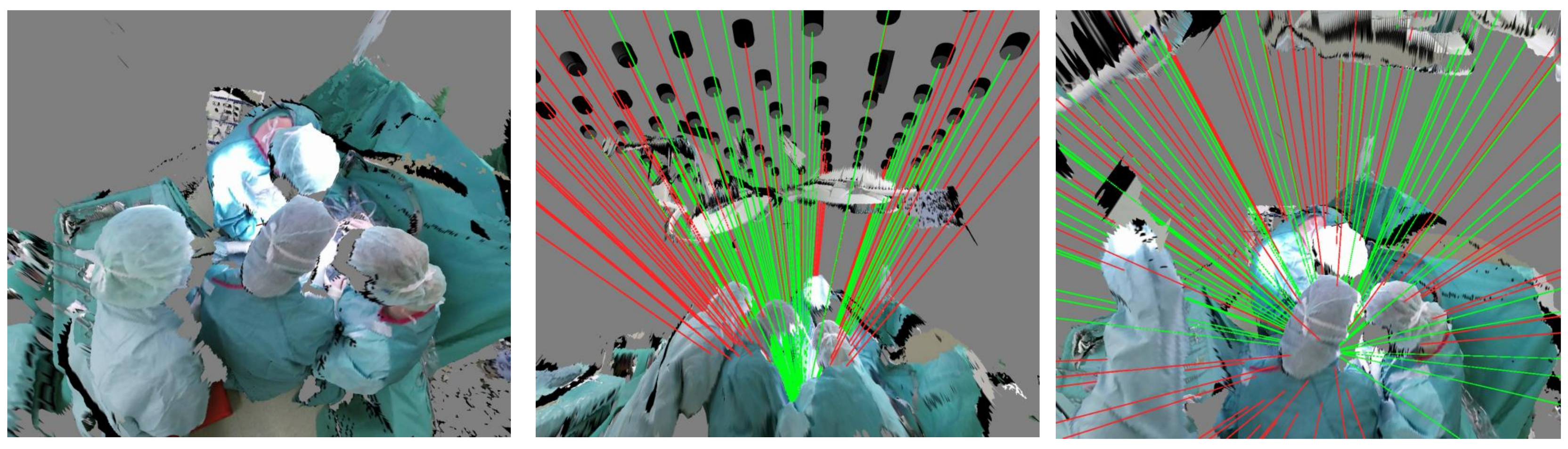

Figure 2. Visualization of the point cloud recording in our simulation software.

For several optimization algorithms (see Table 1), we performed a **leave-one-out cross-validation**. We assume that not more than **50 light modules** are available.

Name	Type	Light Module Count: Initial Count	Light Module Count: Target Count	Initial Arrangement
Greedy (Grid)	Fixed-Layout Problem (a)	100	50	G100 (see Figure 3)
Greedy (Hex)	Fixed-Layout Problem (a)	95	50	H95 (see Figure 3)
SGA	Free Layout Problem (b)	50	50	Random
SADE	Free Layout Problem (b)	50	50	Random

Table 1. Performed optimizations.

RESULTS

The cross-validation results are shown in Figure 3 and Figure 4.

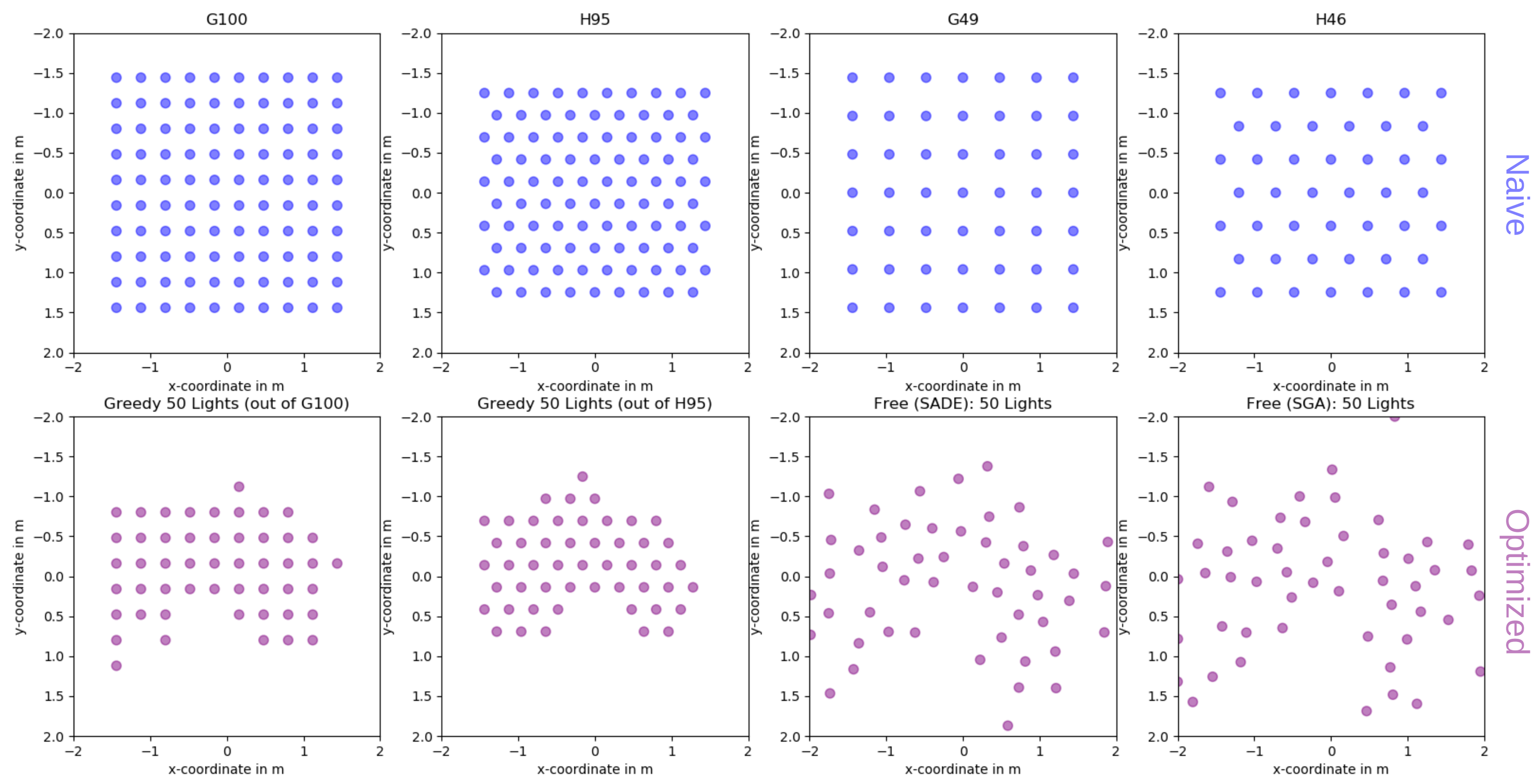

Figure 3. Illustration of the arrangements used in cross-validation for testing on surgery 1.

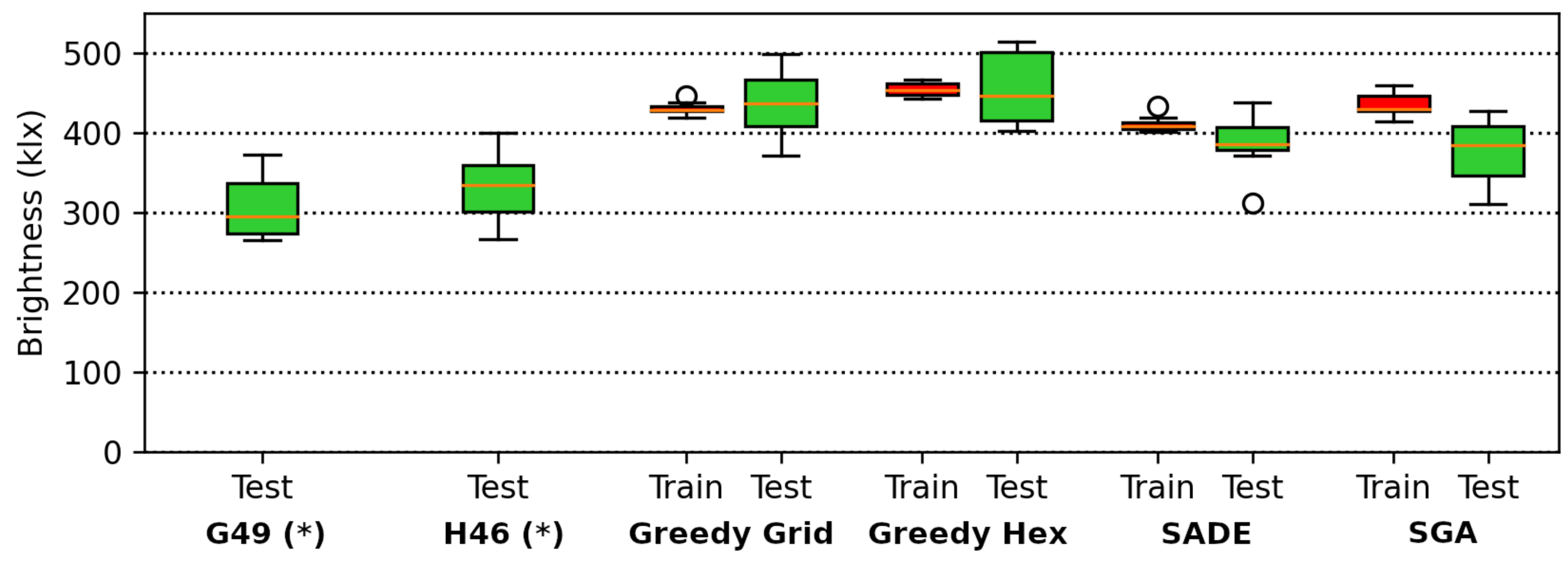

Figure 4. Average results on train and test sets.

Minimum brightness increased **by 41%** (G49 vs. Greedy Grid)

In a preliminary analysis, we examined how often light reaches the site from different positions on the ceiling (see Fig. 5).

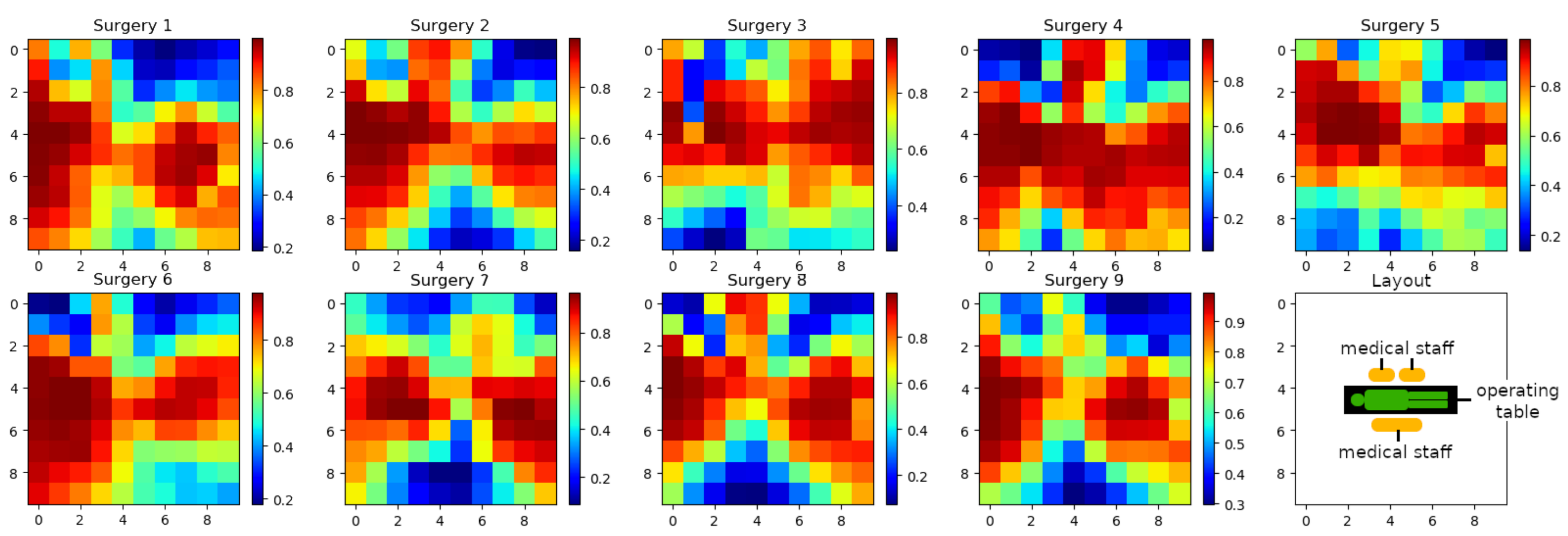

Figure 5. Relative frequency with which a light ray would reach the surgical site from a position on the ceiling during surgery.

CONCLUSIONS

1. We achieve **noticeably higher minimum brightness levels** with optimized light module arrangements during surgery.
2. Based on the results, we assume that optimization may also worthwhile for **other OR rooms** with **different surgery types**.
3. We suggest to consider the optimization of positioning in the **design process** of such new lighting systems.

We might perform new surgery recordings and optimizations as soon as the **SmartOT** lighting system is available for use in real surgeries.