Effiziente Designverfahren für optische Laser- und Beleuchtungssysteme

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LightTrans – A Short Overview

• Founded in 1999
• Offices in Jena
• About 20 employees (together with Wyrowski Photonics)
• Distributors world-wide
  – Europe, United States; Japan, China, Korea
• Customers in more than 30 countries world-wide.
LightTrans - Products

- **VirtualLab Fusion** – software for optical modeling and design.
- **Optical design** and engineering, consulting.
- **Prototyping** of optical components, especially micro-optics.
- **Training** and support for VirtualLab including software and design courses.
Diffractive Diffuser
Holographic Screen

- Master-DOE for recording of a holographic screen side by side with a white paper screen in a airplane Mock-up. The light reflected by the master DOE is clearly brighter than the light reflected by the paper screen.
- Similar technologies can be applied for head up displays.

Pictures by courtesy of EADS, Innovation Works
Dynardo and LightTrans have partnered to integrate the optics design software VirtualLab into the multidisciplinary robust design software optiSLang.

- Partnership has been started in 2015.
- Targets and benefits: robust design of optical and opto-mechanical problems.
Design of Lens Systems: Ray Tracing

Dot diagram
Geometrical and Physical Optics Modeling

- Ray tracing is a powerful method for optical design. Most of the commercial tools are based on ray tracing only.
- Ray tracing has many physical limitations. We have to model on the basis of physical optics!

- VirtualLab Fusion provides both, ray tracing and physical optics field tracing methods in one software.
Design of Lens Systems: Physical Optics

Electric field amplitude: $E_y$

Here

Electric field amplitude: $E_x$

Electric field amplitude: $E_z$

cpu time $\approx 3$ sec
Applications Enabled by Field Tracing

Waveguides and fibers
Volume gratings
\( \mu m \) and nm structures
Crystals and anisotropic media
SLM/Adaptive components
Nonlinear components
Free space
Prisms, plates, cubes...

Light tubes
Scatterer
Diffuser
Lens arrays
DOEs, HOEs, CGHs
Gratings
Freeforms
Lenses

rigorous
approximated
Improvements by VirtualLab + optiSLang

- Access to
  - Benchmark-winning optimization algorithms
  - Advanced statistical methods for data analysis
- Justified workflows including sensitivity analysis, optimization, robustness analysis
- Additional options as
  - Optimization with coupled parameters
  - Usage of derived target functions
  - Pareto design
- Increased performance by meta-models
- Multidimensional visualization
- Cluster computing

- Last but not least:

Get insight to the optical design task.
Connecting optiSLang and VirtualLab

VirtualLab to optiSLang

VirtualLab Fusion
Design Task: Fiber Coupling Laser System

Laser beam, Diameter 4 mm, Wavelength 632 nm

Aspherical lens with radius of 8 mm and conical constant 0.

Single mode fiber, NA = 0.12

Free parameters: distance, radius, conical constant.
Target function to be optimized: fiber coupling efficiency.
Sensitivity Analysis I

- No model for the *Fiber Coupling Efficiency* available.
- Model for *Radius_X* (Beam Radius) is very good (CoP = 99.5%)
- Beam Radius is minimal in valley $\rightarrow$ necessary to obtain high fiber coupling efficiency
Modifications of the Parameter Space

- Dependence between distance and radius in order to achieve high fiber coupling efficiency. The incoupling plane has to be in the focus of the lens.
- From lens design, the formula

$$\text{FocusDistance} = (n-1) \times \frac{1}{R}$$

is known for a convex-plane lens. Here, $n=1.52$.
- Further improvements that have been introduced iteratively after a subsequent sensitivity analysis.
Sensitivity Analysis II

- Introduction of dependent variable leads to a model for Fiber Coupling Efficiency with high CoP.
Approach with optiSLang

- Sensitivity analysis gives us an insight to the topology of the design problem.
- We are enabled to formulate a well defined design problem.
- We learn about the influence of the single parameters on the target function.
- Further robustness analysis is available.
Design Task: Grating Polarizer

Incident angle: 0°
Wavelength: 450 nm - 800 nm

Linear rectangular chromium grating

Period
200 nm

Fused silica

Modulation depth

Slit width

Transmission efficiency of $E_x : \eta_x$
Transmission efficiency of $E_y : \eta_y$
Design Task

- **Free parameters for optimization:**
  - Slit width: 10-190 nm
  - Modulation depth: 20-200nm

- **Merit functions:**
  - Transmission efficiency
  - Uniformity error

- **Constraint**
  - Polarization contrast

\[
U = \frac{\eta_{x,\text{max}} - \eta_{x,\text{min}}}{\eta_{x,\text{max}} + \eta_{x,\text{min}}} \rightarrow \min
\]

\[
C = \frac{\eta_x}{\eta_y} > 50
\]
Approach without optiSLang

- Optimizer can handle single merit functions only.
- Multiple objective have to combined to a weighted merit function.
- Constraints have to be added as penalty terms to the merit function.
Sensitivity Analysis I: Objectives

- Admissible Values: green dots (satisfy the constraint)
- Objectives are contradicting
- → Pareto optimization required
Sensitivity Analysis II

- Parallel Coordinates Plot helps to understand your design

- **Polarization Contrast** is set to 0, a Minimum Efficiency $E_x$ of 97% can be obtained; if set to 50 a Minimum Efficiency $E_x$ of 60% → effect on input side can be immediately seen
Pareto Optimization Results

All designs.

Feasible designs.
Approach with optiSLang

- Understand the behavior of multiple objectives
- Understand the influence of constraints to objectives
- A char of “good designs” as a compromise between both objectives is given
- Decision which design is best for application of interest can be set after optimization

<table>
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<tr>
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<th>Start Design</th>
<th>Best Design Sensitivity Analysis</th>
<th>Best Design Optimization</th>
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<tr>
<td><strong>Maximum Efficiency E_y</strong></td>
<td>0,0073</td>
<td>0,0065</td>
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<tr>
<td><strong>Minimum Efficiency E_x</strong></td>
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<td><strong>UniformityError</strong></td>
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Summary

• optiSLang and VirtualLab together allow a powerful approach to design problems:
  – Optical simulation engines include ray tracing and physical optics
  – Optimization with continuous and discrete parameters
  – Multi-objective optimization (Pareto design)
  – Solving “Understand your design” by sensitivity analysis
  – Make use of optimization and robustness tools which are well established in mechanical engineering for many years.
  – Solution of opto-mechanical design tasks