Neue Entwicklungen in LS-OPT 4.0
– Ausblick auf Version 4.1

New Developments in LS-OPT 4.0 – Outlook V4.1

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Overview

- Introduction/Features of current Version 4.0
- Methodologies – Optimization
- Methodologies - Robustness
- Examples - Optimization
- Examples – Robustness
- Outlook Version 4.1
About LS-OPT

- LS-OPT is a product of LSTC, current version: V4.0
  - major new release with many new feature particularly within the viewer (visualization of results)
  - next presentation “Methoden zur Visualisierung von Ergebnissen aus Optimierungs- und DOE-Studien”
- Beta version 4.1 available by end of this year
- LS-OPT can be linked to any simulation code – stand alone optimization software
- Perfect suitable in combination with LS-DYNA
- Two main products LS-OPT and LS-OPT/Topology
LS-OPT – Overview Methodologies

- Successive Response Surface Method (SRSM)
- Meta-Models
  - Polynomials
  - Radial Basis Functions
  - Neural Nets (FFNN)
- Genetic Algorithm (MOGA->NSGA-II)
- Multidisciplinary optimization (MDO)
- Multi-Objective Optimization (Pareto Front)
- DOE-Studies (ANOVA, Sobol)
- Parameter/System Identification
- Stochastic/Probabilistic Analysis
- Monte Carlo Analysis using Meta-Models
Introduction / Features

LS-OPT – Overview Methodologies

- Mixed Discrete-Continous Optimization
  - Specify sets of discrete variables (e.g. sheet thicknesses)
- Robust Parameter Design (RDO)
  - Improve/Maximizing the robustness of the optimum
- Reliability Based Design Optimization (RBDO)
  - Improve failure probability of optimum
- Visualization of Stochastic Results
  - Confidence Intervals, reliability quantities
  - Fringe of statistic results on the FE-Model
About LS-OPT

- Job Distribution - Interface to Queuing Systems
  - PBS, LSF, LoadLeveler, SLURM, AQS, etc.
  - Retry of failed queuing (abnormal termination)

- LS-OPT might be used as a “Process Manager”

- Shape Optimization
  - Interface to ANSA, HyperMorph, DEP-Morpher, SFE-Concept

- META Post interface
  - Allows extraction of results from any package (Abaqus, NASTRAN, …) supported by META Post (ANSA package)
About LS-OPT

- Parameter Identification Module
  - Handles "continuous" test curves
  - Automated use of test results to calibrate materials/systems
  - Simplify input for system identification applications
  - Visualization of test and simulation curve to compare
  - Confidence intervals for individual parameters in parameter identification

\[
\frac{1}{P} \sum_{p=1}^{P} W_i \left( \frac{F_i(x) - G_i}{s_i} \right)^2
\]
About LS-OPT

- LS-DYNA Integration
  - Checking of Dyna keyword files (*DATABASE_)
  - Importation of design parameters from Dyna keyword files (*PARAMETER_)
  - Monitoring of LS-DYNA progress
  - Result extraction of most LS-DYNA response types
  - D3plot compression (node and part selection)
About LS-OPT

- LS-OPT Supportwebpage -> www.lsoptsupport.com
- Many examples, tutorials, FAQs, HowTos…
Response Surface Methodology - Optimization Process

- Objective values
- Response surface
- Experimental Design points
- Starting (base) design
- Design space
- Subregion (Range)
- Design Variable 1
- Design Variable 2
Find an Optimum on the Response Surface (one iteration)

- Optimization of sub-problem (response surface) using LFOPC algorithm
- Starting value on response surface
- Optimum (computed by simulation using design variables)
- Optimum (predicted by response surface)
Successive Response Surface Methodology

- Design Variable 1
- Design Variable 2
- Design Space
- Region of Interest
- Optimum
- Starting design
Design of Experiments (DOE) - Sampling Point Selection

- Koshal, Central Composite, Full Factorial
- D-Optimality Criterion - Gives maximal confidence in the model

\[
\max \left| X^T X \right|
\]

- Monte Carlo Sampling
- Latin Hypercube Sampling (stratified Monte Carlo)
- Space Filling Designs
- User Defined Experiments
Response Surfaces (Meta Models)

- Linear, Quadratic and Mixed polynomial based
- Radial Basis Functions, Feed Forward Neural Networks and Kriging for global approximations
Methodologies – Robustness Investigations

Stochastic Analysis - Goals

- Statistical Quantities of Output (Response) due to Variation of Input (Parameter)
  - Mean
  - Standard deviation
  - Distribution function

- Significance of Parameter with respect to Responses
  - Correlation analysis
  - Stochastic contributions
  - ANOVA – analysis of variance

- Reliability Issues
  - Probability of failure

- Visualization of statistical quantities on FE-model
  - Spatial detection of variation/correlation

- Introduction/Features
  - Methods – Optimization
  - Methods - Robustness
  - Examples - Optimization
  - Examples - Robustness
  - Version 4.1 / Outlook

New Developments in LS-OPT 4.0, Outlook on Version 4.1 - 16.11.09 • DYNAmore GmbH, Copyright 2009 • www.dynamore.de
Statistical Quantities of Output due to Variation of Input

- Direct Monte Carlo Sampling
  - Latin Hypercube sampling
  - Large number of FE runs (100+)
  - Consideration of confidence intervals for mean, std. dev., correlation coeff.
Statistical Quantities of Output due to Variation of Input

- Monte Carlo using Meta-Models
- Response Surface / Neural Network
- Medium number of FE runs (10 – 30+)
- Number of runs depend on the dimension of the problem (number of variables) and the type of the response surface
- Identify design variable contributions clearly
- Exploration of parameter space -> D-SPEX
Stochastic Analysis - Goals

- Statistical Quantities of Output (Response) due to Variation of Input (Parameter)
  - mean
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CAE-Analysis

Parameter

Response

Feasible range
Significance of Variables

- Correlation Analysis
- ANOVA - Meta-Model based
- Stochastic Contributions – Meta-Model based

Correlation Matrix

<table>
<thead>
<tr>
<th></th>
<th>input output</th>
</tr>
</thead>
<tbody>
<tr>
<td>input</td>
<td></td>
</tr>
<tr>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>-0.17</td>
<td></td>
</tr>
<tr>
<td>-0.01</td>
<td></td>
</tr>
<tr>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>output</td>
<td></td>
</tr>
<tr>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>0.22</td>
<td></td>
</tr>
</tbody>
</table>

important variables
Stochastic Analysis - Goals

- Statistical Quantities of Output (Response) due to Variation of Input (Parameter)
  - mean
  - standard deviation
  - distribution function

- Significance of Parameter with respect to Responses
  - correlation analysis
  - stochastic contributions
  - ANOVA – analysis of variance

- Reliability Issues
  - Probability of failure

- Visualization of statistical quantities on FE-model
  - Spatial detection of variation/correlation
Reliability Analysis

- Probability of failure
- Evaluation of confidence interval
- Prediction error (confidence interval) depends
  - on the number of runs
  - on the probability of event
  - not on the dimension of the problem (number of design variables)

![Graph showing Probability of 8.4% for violating the FORCE-bound](image)
Stochastic Analysis - Goals

- Statistical Quantities of Output (Response) due to Variation of Input (Parameter)
  - mean
  - standard deviation
  - distribution function

- Significance of Parameter with respect to Responses
  - correlation analysis
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  - ANOVA – analysis of variance

- Reliability Issues
  - Probability of failure

- Visualization of statistical quantities on FE-model
  - Spatial detection of variation/correlation
Visualization of Statistical Quantities on FE-model

- Standard deviation of y-displacements of each node (40 runs)

High Variance of y-displacement

Courtesy DaimlerChrysler

RUN 1
Buckling mode A

RUN 8
Buckling mode B
Example I - Optimization

Optimization of an Adaptive Restraint System

Four Different Front-Crash Load Cases (FMVSS 208)

<table>
<thead>
<tr>
<th>Dummy</th>
<th>56 km/h – belted</th>
<th>40 km/h – not belted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid III 5th Female</td>
<td>H305a(ktiv)</td>
<td>H305p(assiv)</td>
</tr>
<tr>
<td>Hybrid III 50th Male</td>
<td>H350a(ktiv)</td>
<td>H350p(assiv)</td>
</tr>
</tbody>
</table>

PAM-Crash Model

- about 500000 elements
- wall clock simulation time \(~19\ h, 4\ cpus, distributed memory\)

Load Case Detection available

- Differentiation of the loadcases \textit{belted} / \textit{not belted} and

  - “Hybrid III 5th Female“ / „Hybrid III 50th Male“ possible

- Trigger time for seatbelt, airbag and steering column might be different
Example I - Optimization

Optimization Problem

- **Objective**
  - *Minimize Thorax Acceleration*
    - \( \rightarrow \text{min BrustA3ms-05a} \)
    - \( \rightarrow \text{min BrustA3ms-50a} \)
    - \( \rightarrow \text{min BrustA3ms-05p} \)
    - \( \rightarrow \text{min BrustA3ms-50p} \)

- **Constraints < 80% of regulation requirements**
  - *Head Injury Coefficient (15ms)*
    - \( \rightarrow \text{HIC15-05a} \)
    - \( \rightarrow \text{HIC15-50a} \)
    - \( \rightarrow \text{HIC15-05p} \)
    - \( \rightarrow \text{HIC15-50p} \)
  - *Thorax Intrusion*
    - \( \rightarrow \text{BrustSx-05a} \)
    - \( \rightarrow \text{BrustSx-50a} \)
    - \( \rightarrow \text{BrustSx-05p} \)
    - \( \rightarrow \text{BrustSx-50p} \)
  - *Femur Forces (left/right)*
    - \( \rightarrow \text{FemurLi-05a} \)
    - \( \rightarrow \text{FemurLi-50a} \)
    - \( \rightarrow \text{FemurLi-05p} \)
    - \( \rightarrow \text{FemurLi-50p} \)
  - *Thorax Acceleration*
    - \( \rightarrow \text{BrustA3ms-05a} \)
    - \( \rightarrow \text{BrustA3ms-50a} \)
    - \( \rightarrow \text{BrustA3ms-05p} \)
    - \( \rightarrow \text{BrustA3ms-50p} \)
Application of Optimization

- Preferred Configuration at AUDI
  - Adaptive Restraint System only for Airbag and Seatbelt
  - Reduction to 9 Variables in total (active=6, passive=3)

- LS-OPT Approach: Successive Response Surface Methodology (SRSM) using linear polynomial approximations
  - 34 runs per iteration
  - D-optimal Design of Experiments (DOE)

- Results
  - 8 iterations - total runs: 276
  - all constraints are fulfilled
  - minimization of multi-objective (second step) not applied
Example I - Optimization

Optimization Progress

<table>
<thead>
<tr>
<th>% aktive</th>
<th>% passive</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

A result which meets all requirements is gained in 8 iterations, each with 34 shots.
Example I - Optimization

Design Exploring with D-SPEX

- Slider controls for interactive browsing
- Variable and response selection

Trigger Time Seatbelt and Force Limit vs. Thorax Acceleration
Parameter Identification of Plastic Material

- Material properties: nonlinear visco-elastic behaviour
- LS-DYNA hyperelastic/viscoelastic formulation - *MAT_OGDEN_RUBBER (#77)
- Hyperelasticity

\[
W = \sum_{i=1}^{3} \sum_{j=1}^{n} \frac{\mu_j}{\alpha_j} (\lambda_i^{\alpha_j} - 1) + \frac{1}{2} K (J - 1)^2
\]

- Prony series representing the viscos-elastic part (Maxwell elements):

\[
g(t) = \sum_{m=1}^{N} G_m e^{-\beta_m t} \quad ; \quad N=1, 2, 3, 4, 5, 6 \quad ; \quad \sigma_{ij} = \int_{0}^{t} g_{ijkl}(t-\tau) \frac{\partial \epsilon_{kl}}{\partial \tau} d\tau
\]
Parameter Identification of Plastic Material

- Minimize the distance between experimental curve and simulation curve
- Least-Squares Objective Function

\[
F(x) = \sum_{p=1}^{P} \left\{ \left[ y(x) - f(x) \right]^2 \right\} \rightarrow \min F(x)
\]
Example III – Optimization

Shape Optimization of a Crash Box

- **Scope of optimization:**
  - minimize the maximum crash force
  - steady-going force progression

- **Shape variation by using Hypermorph and LS-OPT (20 design variables)**

![Graph showing force vs. displacement](image)
Robustness Investigations – Monte Carlo Analysis

- Variation of sheet thicknesses and yield stress of significant parts in order to consider uncertainties
- Normal distribution is assumed
  - $T_{1134}$ (Longitudinal Member) $\text{mean} = 2.5\text{mm}; \sigma = 0.05\text{mm}$
  - $T_{1139}$ (Closing Panel) $\text{mean} = 2.4\text{mm}; \sigma = 0.05\text{mm}$
  - $T_{1210}$ (Absorbing Box) $\text{mean} = 0.8\text{mm}; \sigma = 0.05\text{mm}$
  - $T_{1221}$ (Absorbing Box) $\text{mean} = 1.0\text{mm}; \sigma = 0.05\text{mm}$
  - $SF_{1134}$ (Longitudinal Member) $\text{mean} = 1.0\text{mm}; \sigma = 0.05\text{mm}$
- Monte Carlo analysis using 182 points (Latin Hypercube)
Example I – Robustness

Tradeoff Plot

- Monte Carlo Simulation
- Identification of Clustering

Simulation 185 folding

Simulation 47 buckling

internal energy

sheet thickness $T_{1139}$
Example I – Robustness

Reliability Analysis
- Histogram of distribution
- Probability of exceeding a constraint-bound

Min-Max Curves
- Plot of minimum, maximum and mean history values
- Gives a confidence interval of history values
Example II – Robustness

Design Variables - Uncertainties in Test Set-Up

- Slip Ring Friction \( sfric1 \)
- Pre-Tensioner \( preten \)
- Force Limit Retractor \( forcelimit \)
- Sled Acceleration \( scalaccel \)
- Slip Ring Friction \( sfric2 \)
- Airbag Mass Flow \( scal\_massflow \)
- Steering Wheel \( rot\_stwh \)
- Dashboard \( young\_alu \ x\_transl \ z\_transl \)
### Stochastic Contribution - Results of 30 Experiments

<table>
<thead>
<tr>
<th>Design Variable</th>
<th>Standard Deviation of Design Variable</th>
<th>Standard Deviation Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HIC36</td>
<td>max_chest</td>
</tr>
<tr>
<td>scalaccel</td>
<td>2,5%</td>
<td>3,1%</td>
</tr>
<tr>
<td>sfric1</td>
<td>25,0%</td>
<td>1,3%</td>
</tr>
<tr>
<td>sfric2</td>
<td>25,0%</td>
<td>0,5%</td>
</tr>
<tr>
<td>preten</td>
<td>4,4%</td>
<td>0,0%</td>
</tr>
<tr>
<td>forcelimit</td>
<td>5,6%</td>
<td>1,3%</td>
</tr>
<tr>
<td>rot_stwh</td>
<td>4,8%</td>
<td>0,5%</td>
</tr>
<tr>
<td>transl_x</td>
<td>50,0%</td>
<td>0,1%</td>
</tr>
<tr>
<td>transl_z</td>
<td>50,0%</td>
<td>1,2%</td>
</tr>
<tr>
<td>scalmassflow</td>
<td>5,0%</td>
<td>1,8%</td>
</tr>
<tr>
<td>young_alu</td>
<td>5,0%</td>
<td>0,3%</td>
</tr>
<tr>
<td>all variables</td>
<td>4,3%</td>
<td>2,8%</td>
</tr>
<tr>
<td>residuals</td>
<td>4,7%</td>
<td>1,9%</td>
</tr>
<tr>
<td>Total</td>
<td>6,4%</td>
<td>3,4%</td>
</tr>
</tbody>
</table>
Example II – Robustness

Standard deviation of x-displacements of each node (120 runs)

(a) Deterministic (Meta-Model)

(b) Residual (Outliers)
Outlook – Version 4.1

- LS-OPT/Topology (available end 2009)
  - Nonlinear topology optimization
  - LS-DYNA based
  - Multiple load cases
  - Linear as well as non-linear
  - Design part selection

- Methodology: Hybrid Cellular Automata
  Ref.: Hybrid cellular automata with local control rules: a new approach, Quevedo W., Patel N., Renaud J. (University Notre-Dame, Indiana, USA), 6th World Congress of Structural and Multidisciplinary Optimization, 2005, Brazil
Outlook – Version 4.1

- Generic File extractor
  - Extraction of values from any ASCII input file
- Correlated Input Variables for Stochastic Investigations
- Additional injury criteria (DYNA extraction)
  - IIHS, neck/tibia indices,…
- Full Factorial Discrete
  - Schedule all combinations of discrete variables
- Discrete sampling on a variable basis
Outlook – Version 4.1

- Improved Space Filling algorithm
  - *Greater accuracy: more boundary points*

- Frequency/Mode Tracking
  - Available for NASTRAN
  - MAC and orthogonality criterion

- Global Sensitivity Analysis with Sobol Indices (GSA)

- Pareto Optimal Solutions
  - *Self-Organizing Maps (Ver. 4.1)*

- Many new Features within the “viewer”
  - *e.g. history curves visualization*

\[
\max_i \left[ (\phi_r^T M_r) \phi_i \right]
\]