"optiSLang inside ANSYS Workbench"

- efficient, easy, and safe to use

Robust Design Optimization (RDO)

- Part I: Sensitivity and Optimization

Johannes Will, CEO Dynardo GmbH
Optimization using optiSLang

Extension to ANSYS Design Explorer: DX represent „easy to use“ solution for optimization task’s having 5..10..15 Variables

- with availability of multi disciplinary parametric modeling environments like ANSYS workbench optimization task will be
  - having much more parameter than 10
  - having noisy results and design failure
  - having numerous scattering (uncertain) variables
optiSLang becomes interesting.

Agenda

- Sensitivity Analysis for Large Number of Parameters
- Optimization using Meta Model of Optimal Prognosis
- Applications
OptiSLang Software Environment
Arbitrary CAE-processes can be integrated with optiSLang. Default procedure is the introduction of inputs and outputs via ASCII file parsing. Additionally interfaces to CAE-tools exist.

Connected CAE-Solver: ANSYS, ABAQUS, NASTRAN, LS-DYNA, PERMAS, Fluent, CFX, Star-CD, MADYMO, Slang, Excel,...
Pre and Post Processing

• The Pre Processing
  – Open architecture, user friendly parametrize editor and *one klick solution* for ANSYS workbench support simulation flow setup

• Solving the RDO Task
  – Easy and safe to use flows with robust default settings allows the engineer to concentrate on his engineering part and let optiSLang do the job of finding the optimal design.

• Post Processing
  – The Interactive case sensitive multi document post processing offers the important plots as default
optiPlug - ANSYS Workbench optiSLang Interface

OptiSLang-Plugin: just click to integrate workbench in optiSLang

Parameter Manager

Parameter & Responses
optiSLang inside ANSYS Workbench v14

Modules Sensitivity+MOP, Optimization and Robustness+MOP provide „best practise“ optiSLang functionality
optiSLang Philosophie “safe to use”

Safe to use.
- automate best practice to „black box“ flows
- minimize the risk to miss better designs (optimization)
- minimize the risk to estimate misleading measures for robustness, safety and reliability
- offer easy to use measurements of prognosis quality

That task requires sophisticated technology with carefully balance between number of solver calls and safety to reach the RDO goal.

Technology takes care that “non expert” can use it!
optiSLang inside ANSYS Workbench “Easy to Use”

ANSYS Workbench
easy parametric set up
of complex simulations

Easy to use:
- minimize user input
- offer best practice
defaults for modules
- offer pre defined post processing modes

User-friendliness takes care that it will be used!

- intelligent scanning of parameter space and reduction to important parameter
- generation of Meta model of optimal Prognosis (MOP)
- easy to use optimization and robustness evaluation
optiSLang inside ANSYS Workbench
Easy and safe to use!

What do we mean with that?

- “classic” DOE+RSM technology ask user to reduce number of variables, choose a suitable DOE with a suitable regression function and check the quality of the resulting response surface (RS) and the “optima” on the RS.

- optiSLang provides an automatic flow to reduce variables and generate the best possible response surface for every response with a given number of solver calls [Meta model of optimal Prognosis (MoP)] and checks MoP Prognosis quality and “optima” in real space.
Sensitivity Analysis

(optiSLang 4)

(Design Exploration)
Sensitivity Analysis

- Sensitivity analysis scans the design/random space and measures the sensitivity of the inputs with statistical measures.

- Results of a global sensitivity study are:
  - **Sensitivities** of inputs with respect to important responses
  - **Estimate** the variation of responses
  - **Estimate** the noise of an underlying numerical model
  - **Better understanding** and verification of dependences between input and response variation

- Requirements for our industrial applications:
  - Treatment of a large number of inputs
  - Consideration of strongly nonlinear dependencies
  - Manageable numerical/experimental effort
Sensitivity Analysis
Identifying important parameters

From tornado chart of linear correlations to the dynardo’s Coefficient of Prognosis (CoP)
Statistical measurements

Correlation Measurements
- Coefficients of pairwise linear/quadratic correlation is the simplest correlation measurement
- Multi-dimensional non-linear correlation can be detected using advanced meta models

Goodness of fit Measurements
- Goodness of Fit (Coefficient of Determination - CoD) summarize correlations on the meta models

To solve the tradeoff between dimensionality and number of samples optiSLang includes filter technology to select significant variables (significance, importance & correlation filter)
Limitations of the CoD

- CoD is only based on how good the regression model fits through the sample points, but not on how good the prediction quality is.
- Approximation quality is too optimistic for small number of samples.
- For interpolation models (MLS, Neural Networks, Radial basis functions,..) with perfect fit, CoD is equal to one.
Dynardo’s Coefficient of Prognosis (CoP)

- CoP measures the forecast quality of regression model using an independent test data set.

- Using cross validation and variance indices result in reliable measurements of forecast quality.

- CoP increases with increasing number of samples.
- CoP is suitable for interpolation and regression models.
- Prediction quality is better if unimportant variables are removed from the approximation model.
Meta model of optimal Prognosis (MoP)

- MoP solve following important tasks
  - We reduce the variable space using filter technology = best subspace
  - We check multiple non linear correlations by checking multiple MLS/Polynomial regression = best Meta Model
  - We check the forecast (prognosis) quality using a test sample set = Coefficient of Prognosis (CoP)

- CoP/MoP allows to minimize the number of solver runs
- Final MOP can be used for optimization purpose
Sensitivity Module

**Minimal required user input:**

- Definition of parameter variation
- Number of samples (50 .. 100, Default sampling method (Advanced Latin Hypercube Sampling [ALHS]))
Sensitivity Module

The Meta Model of optimal Prognosis (MOP) is created out of the DOE-Sampling

**Minimal required user input:** non

**Additional features:**
- supports removing designs out of DOE Post Processing
Multidisciplinary Optimization
Optimization Algorithms

**Gradient-based**

**Response surface method**

**Adaptive RSM**

**Biological Algorithms:**
- Genetic algorithms,
- Evolutionary strategies
- Particle Swarm Optimization

**Pareto Optimization**
Gradient-based algorithms

• Most efficient method if gradients are accurate enough

• Consider its restrictions like local optima, only continuous variables and no solver noise

Response surface method

• MOP allows a fast check for design improvement

• Adaptive RSM is the method of choice for a small set of continuous variables (<15)

Natural inspired Optimization

• GA/ES/PS copy mechanisms of nature to improve individuals

• Method of choice for Pareto Optimization Tasks

• Very robust against numerical noise, non-linearities, number of variables,…

When to use which algorithm?
When to use which Algorithm

Optimization Algorithms:
- Gradient-Based Algorithms
- Evolutionary Algorithm
- Pareto Optimization
- Adaptive Response Surface
- global Response Surface

Which one is the best?

Sensitivity Analysis allows best choice!
Sensitivity Analysis and Optimization

1) Start with a sensitivity study using the LHS Sampling

2) Identify the important parameters and responses
   - understand the problem
   - reduce the problem

3) Use MOP+gradient solver for fast Design Improvement

4) Run an ARSM, gradient based or biological based optimization Algorithms
Optimization using MOP

After sensitivity optimization using MOP is supported.

**Minimum required user input:**
- drop the optimization module onto MOP
- defining objective and constraints

“Optima” which are based on meta models need to be verified!

**Proof optima:**
- Automatic verification with real ANSYS call
- Check differences in post processing
Optimization with real design calls

After sensitivity und optimization on MOP the user can continue with gradient-based, NOA-based optimization or ARSM optimization.

**Minimum required user input:**
- define objectives and constraints
- choose method (Gradient-based including start design, NOA-based including best designs’s out of sensitivity/MOP, ARSM in the domain of the most important optimization parameter)

For all optimizer robust default settings are provided.

**NOA - Nature inspired optimization contains:**
- evolutionary, genetic, particle swarm optimization

**ARSM – Adaptive Response Surface Method**
Optimization of see hammer

Dynamic performance optimization under weight and stress constraints using 30 CAD-parameter. With the help of sensitivity study and optimization (ARSM), the performance of a deep sea hammer for different pile diameters was optimized.

Design Evaluations: 200 times 4 loadcase
CAE: ANSYS workbench
CAD: ProEngineer
Optimization of a Large Ship Vessel

EVOLUTIONARY ALGORITHM

- Optimization of the total weight of two load cases with constrains (stresses)
- 30,000 discrete Variables
- Self regulating evolutionary strategy
- Population of 4, uniform crossover for reproduction
- Active search for dominant genes with different mutation rates

Solver: ANSYS
Design Evaluations: 3000
Design Improvement: > 10 % 0
Optimization of a cylinder head

Construction of a parametric cylinder head in SolidWorks

Fluent Mesh in Ansys Workbench

Comparison of Fluent results (red) with real-life flow test => Satisfying results match

Variation of valve seat angles and port geometry to maximize inlet flow

Use of Evolutionary algorithm

Inlet flow enhancement of ≈ 6 % by valve seat, ≈ 14 % through port optimization => Total flow improvement of ≈ 20 %

by courtesy of MicroConsult Engineering
Parameter Update and System Identification
Calibration using optiSLang

1) Define the Design space using continuous or discrete optimization variables

2) Scan the Design Space
   - Check the variation
   - Reduce to sensible parameter
   - Check forecast quality of response measurements
   - Check parameter bounds
   - extract start value

3) Find the best possible fit
   - choose an optimizer depending on the sensitive optimization parameter dimension/type
Identification of material using Digimat

- Identify ANSYS material values with fitting of experiments
- Fitting of experiments: by using Sensitivity Analysis and optimization algorithm the material parameter are identified until accuracy is sufficient

- The whole identification just takes about 30 minutes!

Process: optiSLang-Digimat
Function evaluations: 500
Calibration of seismic fracturing

Sensitivity evaluation of 200 rock parameter and the hydraulic fracture design parameter due to seismic hydraulic fracture measurements

With the knowledge about the most important parameter the update was significantly improved.

Hydraulic-mechanical coupling
Solver: ANSYS/multiPlas
Design evaluations: 160

Blue: Stimulated rock volume
Red: seismic frac measurement