A modular approach for simulation-based optimization of technical systems

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Abstract

A modular web-based approach for simulation-based optimization of multi-physics systems is described. The basic principle is the flexible coupling of an optimization toolbox with a variety of simulators via LAN or Internet. The structure and basic solutions for tool integration, communication, and user interaction are discussed. For a practical optimization task the usability of the approach is shown.

Keywords: Optimization; Microsystems; MEMS; Heterogeneous systems; Multi-physics; Modular optimization system; Distributed optimization via Internet; Finite element method; System simulation

1. Introduction

Usually design optimization of technical systems is based on the designer's experience. With an increasing complexity of systems this approach is not suitable anymore. Simulation is a well-established design method, e.g. for mechanical structures or electronic circuits. The growth of computing performance of modern PCs or workstations offers the possibility to combine numerical methods for parameter optimization and simulation algorithms. If the computing time for the simulation of a single design variant is in a time scale of seconds or minutes, an optimization run can be performed nearly automatically overnight or at the weekend. The most important prerequisites to apply this combination of simulation and optimization algorithms to a technical design problem are from the user's point of view:

- setting up an appropriate, parameterizable simulation model;
- the flexible formulation of the objective function, which often has to handle different design criteria (e.g. for electronics: high speed, low power);
- the user-friendly access to simulation tools and optimization algorithms and their efficient and secure communication.

Today a lot of numerical methods are known for nonlinear parameter optimization. These methods have to be combined with state-of-the-art simulation tools. To apply simulation-based optimization to multi-physics problems, different simulators (e.g. for mechanics, electronics, fluidics) have to be supported.

2. A modular approach for tool coupling in system design

Over the last decade a few powerful commercial frameworks have been established, mostly for the design of electronic systems. Tools for modeling, simulation, synthesis, and optimization are completely integrated in this kind of software systems. Unfortunately, these systems are not very flexible with respect to the enhancement with new optimization algorithms. In the design of micro-electro-mechanical systems (MEMS) or mechatronic systems a combination of two, three, or more simulation tools is needed. In this situation the flexible integration of different simulators and other design tools in an optimization infrastructure is necessary, which provides flexible tool coupling and data exchange. In the field of numerical optimization a lot of research was performed in the last few years and various frameworks are available, too: AMPL, BOSS quattro, GAMS, iSight, modeFrontier, MODOS, OPTIMIUS, PLATON, and others.

However, to meet the special requirement from industrial applications in the MEMS and mechatronics area we decided to develop MOSCITO – *a modular*

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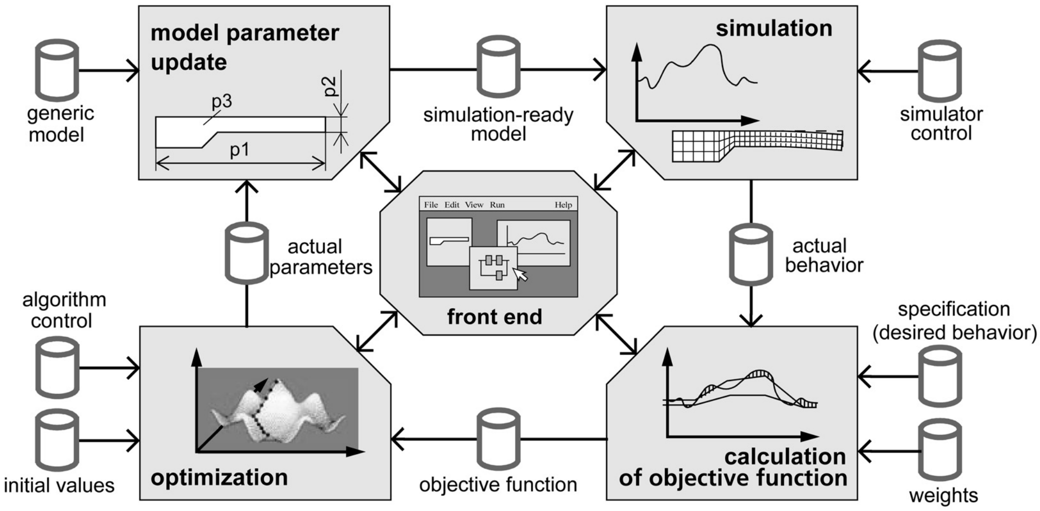

Fig. 1. Simulation-based optimization cycle.

simulation-based optimization system (Fig. 1, http://www.eas.iis.fhg.de/solutions/moscito/) [1,2].

MOSCITO aims at a completely modular and flexible web-based approach for tool coupling. That means, tools can be arranged in almost every user-defined workflow and they are coupled via LAN or the Internet. This approach allows the definition of more sophisticated optimization tasks, e.g. parallel calculation of cost function, combination of two or more simulators for multi-physics simulation etc. Furthermore, our approach is characterized by the following features:

- availability of a variety of optimization algorithms (local and global, direct and with gradients, with and without bounds);
- automatic parameterization of the system model ('updating'),
- flexible integration of tools for multi-level and multi-physics simulation (from system level to FEM);
- user-definable objective functions;
- communication via the Internet – each module may reside on different computers in different locations distributed over the world;
- data exchange between the modules via standard protocols;
- encryption capabilities for transfer of data.

At present the following simulators are supported by implemented interfaces and model parametrization modules: Matlab/Simulink, ANSYS, Dymola, Saber, Eldo, SPICE, AdvanceMS and Dynast.

The optimization algorithms implemented and integrated in the system can be divided into *local algorithms:* Nelder-Mead Simplex, BFGS (Quasi-Newton), L-BFGS-B (Quasi-Newton with restricted memory), Powell, N2FB (Levenberg–Marquardt), Conjugate Gradient, FSQP (Feasible Sequential Quadratic Programming), Praxis (Powell algorithm modified by Brent), and *global methods:* Simulated Annealing, DIRECT (DIviding RECTangles), BTRK (Boender, Timmer, Rinnooy Kan, and Strougie). They are derived from textbooks [3,4] or libraries [5].

3. Tool integration

The basic idea is to separate the coupling software into a *communication layer* which is responsible for data exchange and an *integration layer* for handling all interactions with an integrated tool [6].

The *communication layer* is based on TCP/IP sockets. Content data (netlists, simulation results, initial parameter values) and control information (configure, initialize, start/stop of simulation tools) are transferred as XML streams or Java serialized objects. The *integration layer* is represented by the *MOSCITO Agent* which handles serialization, encoding and conversion of data, and serves as a wrapper between communication layer and an integrated tool. It hides all tool-specific properties and provides a unified interface. An agent can use different communication mechanisms for controlling the embedded tool: files, named pipes, sockets, stdin/stdout pipes or higher protocols using CORBA or COM/DCOM object models.

The MOSCITO software has been implemented in Java and runs on SUN workstation (Solaris) and on PCs (Microsoft Windows and LINUX).

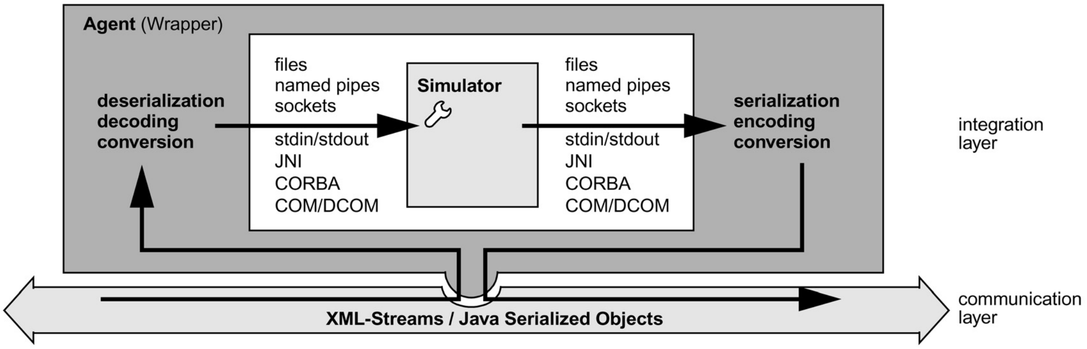

Fig. 2. Communication layer and integration layer.

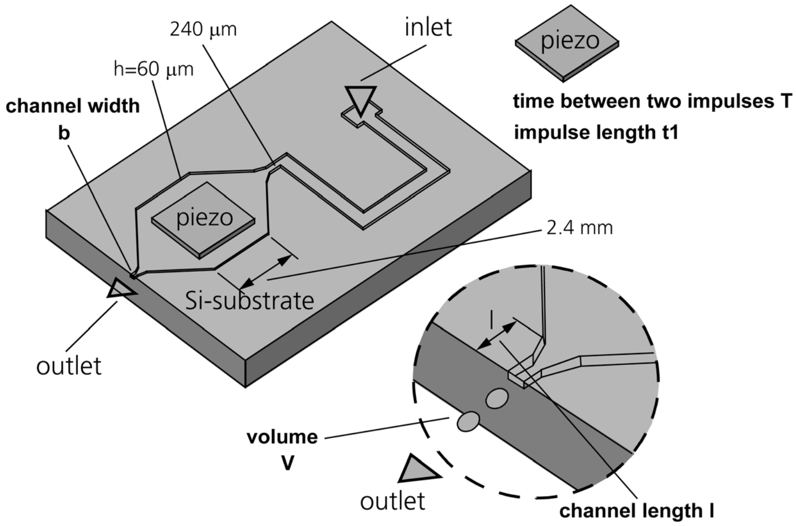

Fig. 3. Valveless micropump.

4. User interactions

The *MOSCITO Desktop* is the graphical user interface of the MOSCITO integration platform. A user has access to all registered agents in a network. The *MOSCITO Desktop* provides the following functionality:

- configuration via a MOSCITO project file;
- predefined workflows for typical design tasks;
- browser support for configuration;
- console window for error messages and for observation of optimization progress.

The visualization module *MOSCITO Scope* supports the display of result data (simulation results, parameter values, objective function, etc.).

5. Application example

The described approach was applied to several design tasks, e.g.:

- shape optimization of a force sensor;
- filter design in electronics;
- shape optimization of suspension beams for micro mirrors;
- geometry optimization of an ionization chamber for thickness measurement of material;
- parameter adjustment for the magnetic part of a micro relay to fit measured data.

In the following an application is described. The valveless micropump shown in Fig. 3 is produced using an anisotropic etching process [7]. A piezoelectric element on the pump chamber membrane is driven by an electrical voltage. This causes a deformation of the membrane and a flow of fluid through the channels. Due

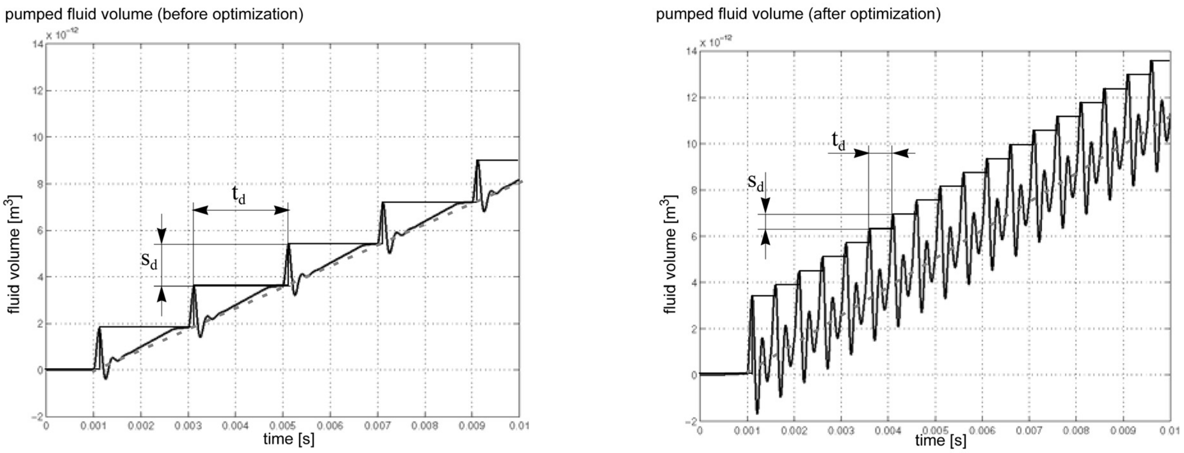

Fig. 4. Optimization results.

to the extremely nonlinear behavior of the pump outlet it ejects droplets which are in the range of nanoliters. The micropump is used in analyzing and proportion systems for chemical and pharmaceutical applications. Subject of the optimization is to maximize the fluid volume ejected by the pump. The parameters for the optimization are:

- t1 – length of electrical impulses;
- T – the time between two impulses;
- b – the width of the outlet; and
- 1 – the length of the outlet.

Figure 4 shows the behavior before and after optimization. The oscillating curves represent the integral of flow rate at pump outlet, the ejected droplets are marked by a step pattern.

The fluid volume ejected by the pump, which is proportional to the slope of oscillating curves (dotted line), was increased by 20% as a result of the optimization using MOSCITO. This result was achieved using the Nelder–Mead-Simplex algorithm in about 40 iterations. It is to be seen that the number of droplets was increased, the time t_d between the droplets and their size s_d was decreased. Due to changes in the outlet geometry, the size of the first droplet (at $t = 0.001$ s) was increased for the optimized structure.

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