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Collaborative Framework for Multiscale Design of mkFluidic BioMEMS

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Abstract

Engineering design of pure multidisciplinary and multiscale devices, like bioMEMS is still a challenge, even with modern CAD/CAE tools, because of the necessity of deep expertise knowledge in all multiphysics domains. Actual research propose an structure of heterogeneous collaborative design platform for the computer-aided support of multiscale simulation and design process. A prototype of collaborative framework was developed.

Keywords: CAD/CAE/CAM, collaborative framework, multiscale design, bioMEMS.

1. Introduction

Most of modern micromechanical engineering objects, including microelectromechanical systems (MEMS), bioMEMS and μFluidic devices are multiphysics, multidisciplinary and multiscale by its nature. Typical MEMS design process requires designers and experts from different MEMS domains, like mechanics, electronics, materials, optics, chemistry, biology, etc. Solution may be obtained in a new workflow model, based on distributed collaborative design process, supported by dedicated software framework. Over last decade collaborative design framework becomes the key technique for complex product development, especially in case of highly multidisciplinary objects and systems. MEMS is a common example of such devices. The whole area of microfluidic bioMEMS and other nanotechnology devices often includes completely inseparable domains, because of necessity of storing, preparing, transporting, reacting, detecting, separating and others diagnostic procedures. Thus, the information sharing and model processing among different multidisciplinary domains usually becomes a bottleneck of complex product workflow and collaborative design process.
The main preconditions of collaborative design are based on:

- Deep specialization and territorial distributing of design groups;
- Complicated multidisciplinary and multiscale nature of designed objects;

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- Wide diversity of CAD/CAE/CAM tools, used in design process.

2. Multiscale design of complex BioMEMS devices

Recent years a significant activities in microsystems research has shifted from pure MEMS to bio-MEMS and microfluidic microsystems, primarily because of the wide potential applications of these devices in chemistry, biology, medicine and veterinary. In order to link understanding between the multiphysic processes (mechanical, physical, chemical, biological) at micro & nano scales and macroscale performance of MEMS devices, a new multiscale design concept was developed [D.L.McDowell, et al., 2009].
Let's consider microfluidic diagnostic MEMS, which implement functions of mixer, reactor, injector, detector and separator in one microdevice. The principle scheme and topology sketch of such microfluidic MEMS with electrokinetic control is presented. This unit is drafted to implement typical biochemical laboratory functions - preparation, analysis, diagnostics and separation of biochemical substances [J.Dziuban, et al., 2011].

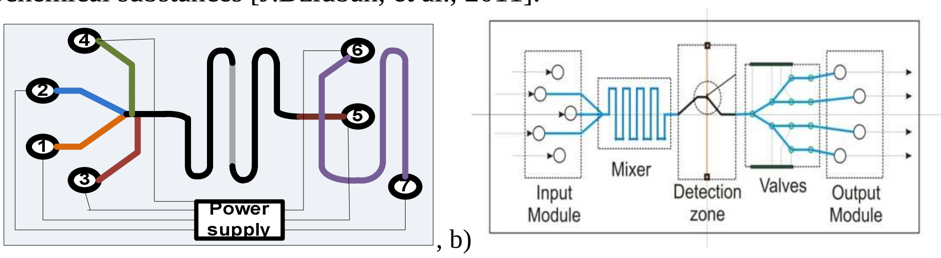
a)  , b)

Fig. 1. Diagnostic electrokinetic microfluidic device.

A typical top-down design of such devices includes following stages:
1. Creating a protocol for selected biochemical processes (bio-CAD).
2. Defining kinetics and thermodynamics of biochemical processes (chem-CAD)
3. Developing optical detection method for biochemical diagnostic (optical CAD).
4. Developing systematic behavioral model (system and functional design), based on bio-protocol and optical diagnostic methods (CoFluent, VHDL-AMS, etc).
5. Topology and layout design by using various specialized MEMS CAD tools.
6. Parametric synthesis and simulation design of device regimes (Ansys, Comsol).
7. Designing technological masks, software instructions and manufacturing equipment for milling and embossing machines, etc.
8. Validating, testing and verification macroscopic behavior of newly designed MEMS prototype.

Despite the simple structure of this MEMS device, design engineer must calculate the configuration, geometric dimensions, temperature, biochemical kinetics and hydrodynamic flow parameters. In addition, the reaction chamber should be optimized to support a variety of mixed flows, a certain temperature profile

specifically designed for the chamber, a set of valves for automatic switching among channels, etc.
A typical consequent design workflow for bioMEMS devices presented on Fig. 3.

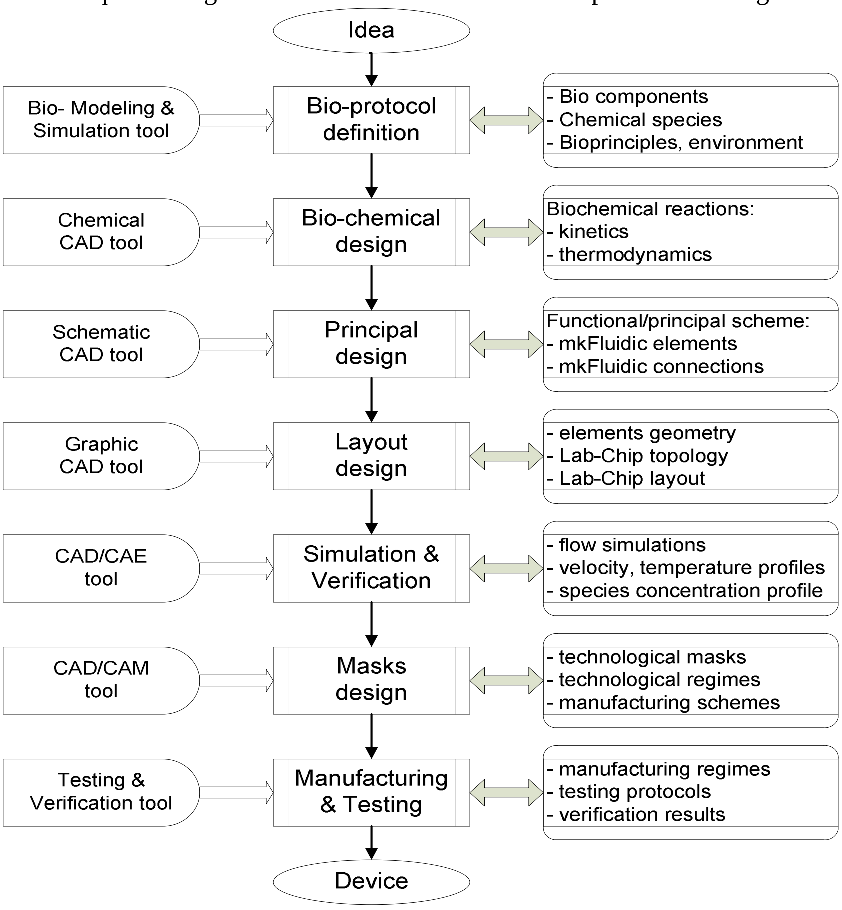


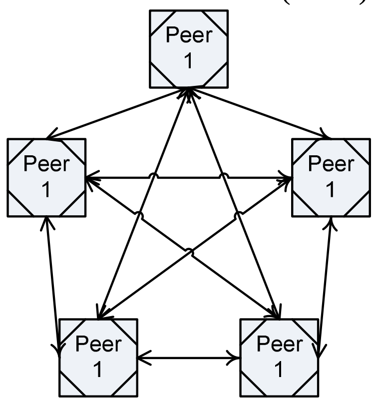
Fig. 2. Simplified design workflow for bioMEMS devices.

This simplified scheme didn't depict iterations and reverse cycles among stages. It is done to shown a broad variety of CAx tools, used for modeling, simulation, design, engineering and manufacturing of bioMEMS devices. The list of these tools usually include e-Cell, Thinker Cell, AutoCAD, Zemax, BioCAD, Micado, CAD/Art, TannerEDA, Coventor, Intellisense, MEMS Pro, CoFluent, Ansys, Comsol, etc. All these software tools, which covers mechanical, chemical, biological, electronic, optic and other domains, should be able to collaborate and exchange data in multiple iteration cycles. Thus, main challenge in bioMEMS design is data exchange and knowledge integration standards among design procedures, especially in case of multi-disciplinary design and heterogeneous CAD tools. Requirement of multiple reuse of project information in various tools leads to the idea of presenting joint design data in a structured neutral format. Then project file can be easily modified, updated and transferred between all CAD/CAE/CAM systems. Such neutral format of design data was created together with software communication platform, which forms collaborative design software framework.

3. Collaborative design technologies

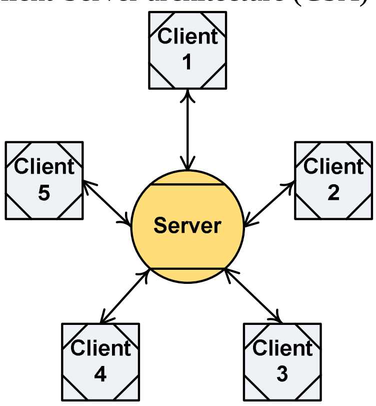
Collaborative design process of complex multiphysics devices requires specific distributed architecture of the collaborative framework in order to solve the main tasks and challenges of collaborative design. All collaborative frameworks and distributed systems adopt one of following network architectures: peer-to-peer, client-server or service-oriented [H.Aziz, et al., 2005]:

• Peer-to-Peer architecture (P2PA)



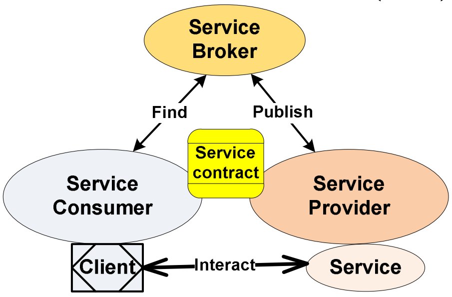
It allows decentralized design among few independent participants. All involved peers directly send each other all updates, related to the modifications in virtual design model, and each of them maintains separate simulation engine. This type of architecture is applicable in case of simple design objects. Synchronization issues can arise when extended and complex elements appears in the project, and it may be a challenge to resolve it without collaboration server.

• Client-Server architecture (CSA)



A central server supports virtual design model and delivered design updates to all involved stakeholders. Client workstations update their local representation according to updated project data and sends its own interactions to the server for distributing. It is robust against jitter and latency, but can suffer from wrong order interactions missed design data and inconsistent view from multiple clients. CSA requires reliable network connections, powerful server and light-weight client applications.

• Service-Oriented architecture (SOA)



Recent paradigm in collaborative distributed design systems, which incorporates loosely-coupled, extendible and flexible systems. It comprised of elements that can be categorized into functional and quality of service. By reusing basic components – services, it offers flexible, cost-effective and reliable services for end-user applications.

Due to the multidisciplinary nature of design objects, actual research was based on recent and most advanced hybrid architecture, which combine client-server and SOA elements [Y.Wang, B.O.Nnaji, 2006]. The main components to such CAD collaborative systems include:

1. Single-user CAD/CAE/CAM tools with extended API support, which allows programming control of internal functions and procedures;
2. Specialized collaboration adaptor, which bridges involved CAD/CAE/CAM tool with collaboration network;
3. Server-side collaboration engine, which provides application-independent collaboration capabilities and techniques.

4. Collaborative framework for BioMEMS design

Collaborative design framework is relatively new paradigm for CAD/CAE/CAM systems, which based on global, network-centered and spatially distributed environments [J.Y.Chen, et al., 2005].

Collaborative design process is carried out by a team of designers in a joint representation of project requirements, drawings and documents. Each user may have own CAD/CAE/CAM tool with installed custom-developed local CAx collaborative module, based on native API part of commercial system.

The Document Object Model of the developed collaborative design framework includes three main components: (1) geometric representation in a form that allow its visualization in any workstation, (2) parametric representation, which allows any CAx system to initialize mathematical simulation, (3) complex representation of the project design information, which allows to reconstruct all design process.

Since the task of actual research was to support a synchronous collaboration design and the reduction of the network-traffic was extremely important, hence only latest changes in Document Object Model should be converted in compressed neutral format, based on XML schema. Local CAx module identified changes in local design, check user's permissions and pass these changes to neutral file converter. Besides step-by-step changes, a local copy of complete design model is stored in local file repository of each workstation.

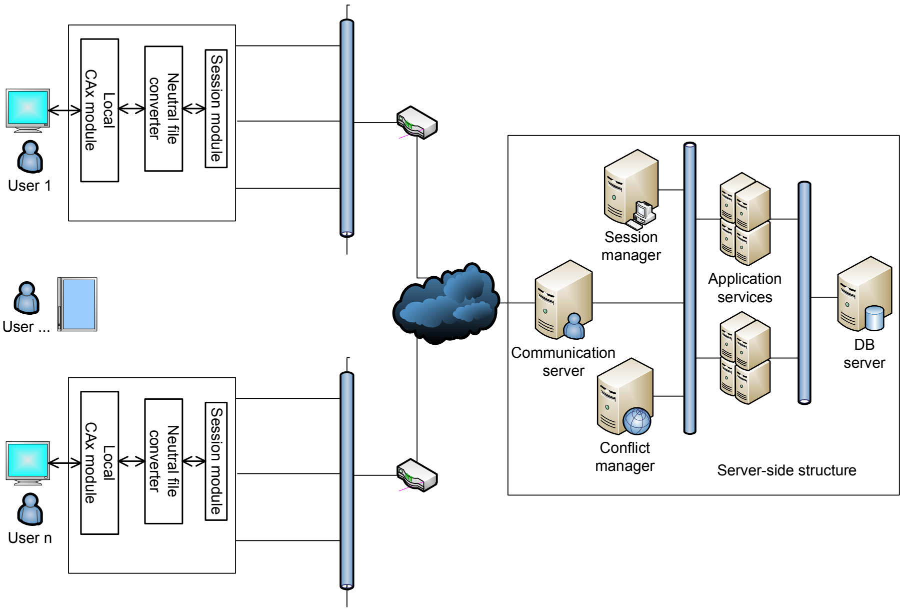


Fig. 3. Structure of collaborative-design framework.

Collaboration server consist of four levels [O.Matviykiv, et al., 2007]: (1) Communication server, which supported connections between clients; (2) Session and Conflict managers, which controls user's rights and resolve organizational and technical design conflicts; (3) Application services, which realize the kernel of collaboration engine; and (4) DB server, which store complete representation of Document Object Model with whole design history.

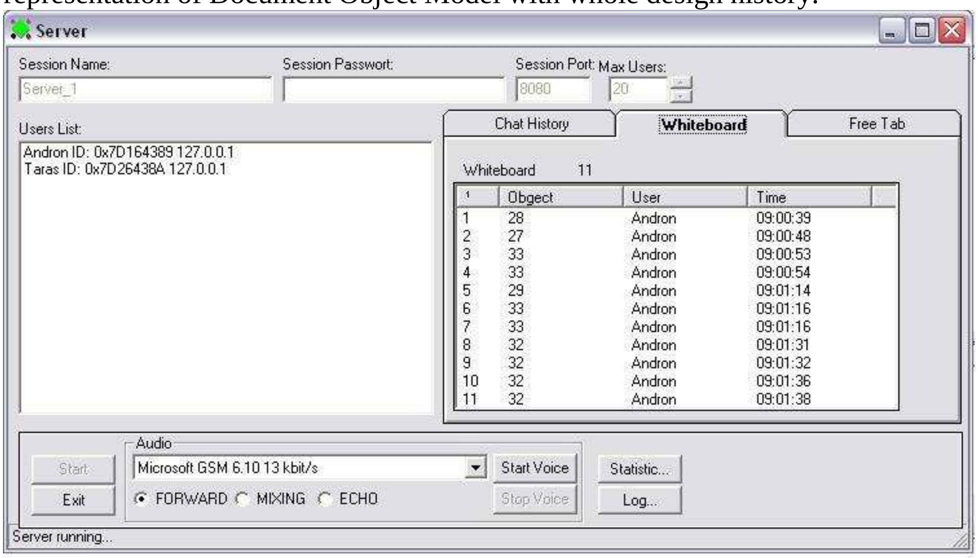


Fig. 4. Main collaboration server window.

Actual implementation of collaboration server support up to 8 independent design sessions and maximum 20 clients in each session. The list of users is visualized according to registered ID numbers and IP addresses. Complete design protocol with list of design steps is visualized in appropriate history windows.
Additionally, collaboration server provide a possibility to create an explicit model from the procedural design history, and deliver it via the network in viewable graphic format to clients with mobile devices and limited computer resources. This option allows easy communication for all stakeholders and guarantee every person real-time collaboration in design process together with product designers.

5. Conclusions

Collaborative CAD/CAE/CAM framework represents an environment, which provides engineers from multiple domains the ability to maintain synchronous design works upon joint technical object in real-time. It is based on SOA and may include different commercial and custom-developed CAx tools.
The framework consists of modified working places, specialized commercial CAx tools, custom-developed format converters, SOA-based communication platform, communication server with various collaboration services and protocols. Combining all these complementary technologies allows to implement a prototype of heterogeneous framework for distributed collaborative design of complex multiphysics objects and systems, which was tested on microfluidic BioMEMS devices. The great feature of proposed framework is flexibility and its orientation on multiscale characteristics of designed object.

References

D.L.McDowell, J.Panchal, H.-J.Choi, C.Seepersad, J.Allen, F.Mistree, 2009, Integrated Design of Multiscale, Multifunctional Materials and Products, *Butterworth-Heinemann*, ISBN 0080952208, 2009.

J.Dziuban, M.Lobur, O.Matviykiv, 2011, Computer-Aided Diagnostic Tool for Biomedical Microfluidic Lab-Chip Devices, Proc.of the XI-th International Conference CADSM’2011, Lviv - Polyana (Ukraine), 222-223, 2011.

H.Aziz, J.Gao, P.Maropoulos, W.M.Cheung, 2005, Open standard, open source and peer-to-peer tools and methods for collaborative product development, *Computers in Industry*, 56(3), 260-271, 2005.

Y.Wang, B.O.Nnaji, 2006, Document-Driven Design for Distributed CAD Services in Service-Oriented Architecture, *Journal of Computing and Information Science in Engineering*, 6, 127-138, 2006.

J.Y.Chen, Y.S.Ma, C.L.Wang, C.K.Au, 2005, Collaborative Design Environment with Multiple CAD Systems, *Computer-Aided Design & Applications*, 2, 1-4, pp 367-376, 2005.

O.Matviykiv, M.Lobur, O.Lebedeva, 2007, Virtual Collaborative Design Environment for Distributed CAD Systems, Proc. of the IXth International Conference CADSM, Lviv-Polyana (Ukraine), 538-541, 2007.