Computers in Industry 65 (2014) 786–795

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

Insights from developing a multidisciplinary design and analysis environment

Chengen Wang *

State Key Laboratory of Synthetical Automation for Process Industries, Northeastern University, 3 Wnhua Road, Shenyang, China

ARTICLE INFO

Article history:
Received 18 December 2013
Received in revised form 15 February 2014
Accepted 19 February 2014
Available online 14 March 2014

Keywords:
Multidisciplinary design and analysis
Application and information integration
Collaborative design
Parametric geometric modeling

ABSTRACT

This paper presents technical insights gained from developing a multidisciplinary design and analysis (MDA) environment, which proficiently integrates, coordinates and controls disciplinary software packages, data sources, and human factors. The MDA environment cost-effectively boosters global optimization of product design problems by means of integrating and coordinating engineering resources, implementing optimization approaches, and reconciling contradicting disciplinary objectives. This paper begins with depicting a multidisciplinary view of a generic complex engineering system, which sets the basic tone of developments of the environment. Subsequently, this paper proceeds with descriptions of information techniques or software utilities that constitute core competencies of the MDA environment. Firstly, software components based integration techniques are implemented to enhance interoperability among heterogeneous engineering applications and data sources. The integration techniques have viably overcome engineering inefficiencies, system incongruences, and information inconsistencies caused by 'automation islands' problems. Secondly, project and workflow management utilities are developed to support collaborative design, which allows better utilization of engineering resources and effective coordination. Thirdly, tailored geometry modeling techniques are implemented to enable expeditious representations of shape variations in congruence with outcomes of multiphysics analyses and simulations. Fourthly, optimization strategies, sensitivity analysis, surrogate models and searching algorithms are coded to enable global engineering optimization. Finally, this paper concludes with insights gained from developments of the MDA infrastructure.

1. Introduction

Rapidly changing market demands for high performance products force companies to solve complex engineering problems in a more tightly integrated, coordinated and optimized way. Actually, since the early applications of information systems to manufacturing industries researchers have kept on looking for cost-effective integration approaches [1]. Integration combines individual applications into a seamless whole, enabling business processes and data to communicate with one another across applications [2]. Effective integration lays a concrete foundation for collaboration and optimization approaches to appropriately address extensive interactions among multiple disciplines, such as aerodynamics, thermodynamics, and structure analysis.

Collaborative design supports sharing product data and know-hows, and providing collaborative tools to bring the multidisciplinary team together [3]. Using collaborative engineering, the collocated team is replaced with an interactive team structure where the team members are geographically distributed and the best engineering talent can be applied to the design effort regardless of physical location [4]. In collaborative engineering environments, agents or intelligent software components are primary means of wrapping up legacy software codes, transparently interoperating on heterogeneous data sources, mediating design and analysis processes, and enabling communications among engineers. Specifically, an interface controller or mediator agent collects boundary values, dynamic/shape coordinates, and parameters/constraints from neighboring subdomains and adjusts boundary values and dynamic/shape coordinates to better satisfy the interface conditions [5].

Furthermore, steadily growing interest in an overall system optimization, instead of disciplinary level optimums, gives rise to multidisciplinary design optimization (MDO) methodology, and accelerates its industrial applications, particularly in aerospace industries [6]. And, MDO applications were increasingly reported in numerous industries, including aircrafts [7], gas turbines [8], rail

* Tel.: +86 24 83683619.
E-mail address: 2013.c.wang@ieee.org

http://dx.doi.org/10.1016/j.compind.2014.02.015
0166-3615/

vehicles [9], and a solid propellant launch vehicle [10], just to name a few.

A characteristic engineering project in aerospace industries demands computations of aerodynamics, heat transfer, structural mechanics and dynamics problems. Naturally, strategies are required to manage disciplinary couplings, to coordinate system interactions, and to reconcile goal-conflicts among sub-optimizations. Classical MDO strategies include all-at once (AAO), individual discipline feasible (IDF), multiple discipline feasible (MDF), Simultaneous Analysis and Design (SAND), concurrent subspace optimization (CSSO), bi-level integrated system synthesis (BLISS), collaborative optimization (CO), etc. [9,11–13].

A remarkable hinder to global optimizations of large-scale engineering problems is prohibitive computation costs of iteratively simulating physical processes governed by the conservation laws, which are mathematically formulated by Partial Differential Equations (PDE). To circumvent the hinder, engineers often use less computation-expensive surrogate models to approximate response of high fidelity models, reducing computational loads of running PDE solvers. And, a variety of surrogate models or metamodels were presented in the previous literature, such as polynomial response surfaces, kriging models, radial basis functions, neural networks, multivariate adaptive regression splines [14,15].

Conceivably, large-scale engineering environments or information platforms have to incorporate searching algorithms for running disciplinary optimization computations. Normally, gradient-based searching methods have evident merit of high computation efficiency because they provide guidance information to the searching processes. However, the potential use of gradient-based methods is hampered by limitations like requirements of explicit knowledge of problem formulations. On the other hand, evolutionary methods, such as genetic algorithms (GA), do not need directional information and work with a population of candidate solutions rather than a single solution, which avoid being trapped in local optima as long as the diversity of the population is well preserved [16].

It is significantly advisable that the aforementioned informatics techniques be collectively implemented, which gains more technical benefits than individually applying the techniques. Consequently, a software environment is needed to accommodate, manage and control the numerous applications used for achieving multidisciplinary design optimizations [17]. Such a software environment may be interchangeably refereed as a platform, infrastructure, architecture, and framework in the literature. Reports on developments of myriad software environments for complex engineering problems take a conspicuous place in the literature.

In the early 1990s, NASA Langley Research Center sponsored the development of an in-house framework called Framework for Interdisciplinary Design Optimization (FIDO) [18]. Also in NASA Langley Research Center, a collaborative engineering environment (CEE) was developed to enable the Agency's engineering infrastructure to interact and use the best state-of-the-art tools and data across organizational boundaries [4]. Houstis et al. presented the architecture of an agent-based software framework for the simulation of various aspects of a gas turbine engine, utilizing a "network" of collaborating numerical objects through a set of interfaces among the engine parts. Their framework, also called a multidisciplinary problem solving environment (MPSE), used a general wrapper method for encapsulating FORTRAN or C code as an agent library [5].

From the beginning of this century, we have been studying and developing a wide spectrum of techniques that support collaborative multidisciplinary design and analysis of aeroengines, aircrafts, and other products. Previously, we described the research from different perspectives, such as information and application integration [17,19–21], parameter mapping [1], data management [22], product lifecycle modeling [23], project scheduling [24], searching algorithms [25,26], applications to turbine design [27] and blade design [28]. To facilitate industrial applications, we have developed an MDA environment to incorporate the aforementioned techniques and other pertinent techniques. Justifications of developing an in-house environment instead of adopting commercial platforms include controllable budgets, flexible extensibility, high reconfigurability and adaptability to specific industrial requirements.

The goal in writing this paper is twofold. First, we try to outline a panoramic picture of the MDA environment that encompasses the necessary tools enabling multidisciplinary design collaboration and optimization. Second, we try to disseminate our know-hows gained in developing and implementing the MDA environment, which may be referenced for similar development initiatives.

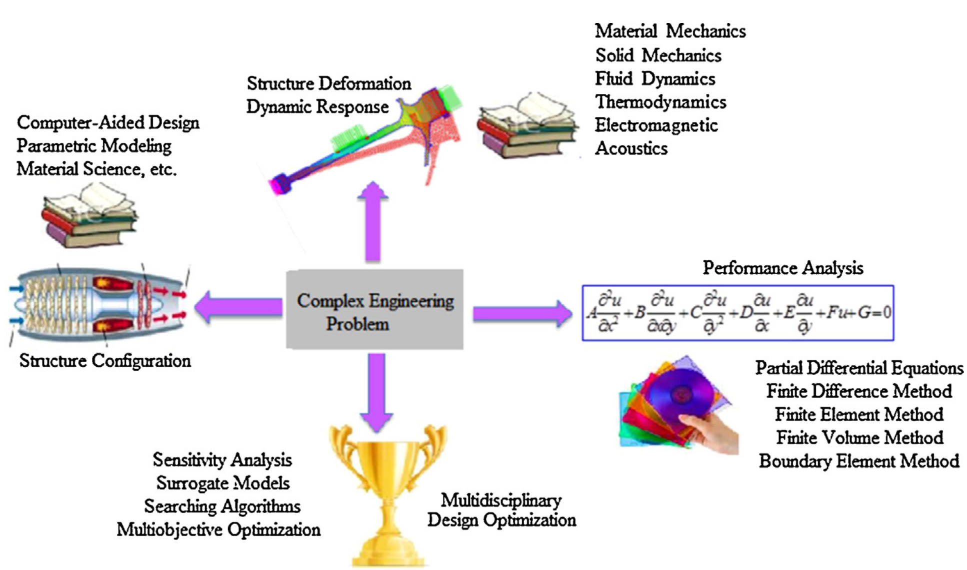

Fig. 1. Multidisciplinary view of a generic complex engineering system.