Ocean Engineering 147 (2018) 517–530

Contents lists available at ScienceDirect

Ocean Engineering

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

A new approach in system and tactic design optimization of an autonomous underwater vehicle by using Multidisciplinary Design Optimization

Mohsen Bidoki, Mehdi Mortazavi *, Mehdi Sabzehparvar

Amirkabir University of Technology, Tehran, Iran

ARTICLE INFO

Keywords:
Multidisciplinary design optimization
Autonomous underwater vehicle
MDF
PSO
Tactical subspace

ABSTRACT

Optimal design of an Autonomous Underwater Vehicle (AUV) consists of various subsystems and disciplines such as guidance and control, payload, hydrodynamics, power and propulsion, sizing, structure, trajectory and performance. The designed vehicle is also employed in an operational environment with tactical parameters such as distance to target, uncertainty in estimation of target position and target velocity. Multidisciplinary Design Optimization (MDO) is the best way for finding both optimum and feasible designs. In this paper, a new optimization design framework is proposed in which Multidisciplinary Feasible (MDF) as MDO framework and Particle Swarm Optimization (PSO) as optimizer were combined together for optimal and feasible conceptual design of an AUV. Initially, we found an optimal system design by using MDF-PSO methodology in engineering space for any single tactical situation (locally tactical parameters). Then the optimal off-design AUVs in tactical subspaces were found by minimizing the difference between the locally optimized objective function and suboptimal objective function. In this framework, we have shown that not only is the tactical situation affected by AUV design parameters, but an optimal AUV for each tactical regions are also found.

1. Introduction

In recent years, the application of Autonomous Underwater Vehicle in many research domains such as underwater exploration and undersea warfare has developed. In the design of an AUV many engineering design fields such as hydrodynamics, propulsion, Guidance, Navigation and Control (GNC) and structure have been involved. Finally, designed AUV has been launched from a platform and it has been employed in operational environment. The simultaneous application of these engineering fields increases the complexity of AUV's design and tactic.

Today, the traditional design of a complex system that is employed in a bigger system has been outmoded and engineers are researching for new paradigms to solve design problems. Thus, the design process of these systems is changed when new paradigms and techniques are created.

There are many important parameters for designing an AUV such as velocity, range, payload, propulsion system parameter, guidance and control parameters, hydrodynamic, sonar, target detection parameter, tactical parameters that increase the complexity of the design process and coupling between subsystems or disciplines (Belegundu et al., 2000; Yukish et al., 2000; Frits, 2004; McAllister et al., 2002; Fitzgerald et al., 2002; Benanzer et al., 2008; Zhang et al., 2013).

Complexity and hard coupling between these disciplines increase the computational burden and processing time of the design optimization process.

There are many techniques for designing an AUV such as stochastic methods, multiobjective methods and reliability-based methods. In recent years, engineers have tended towards using Multidisciplinary Design Optimization (MDO) methods for designing the complex system. Designers can simultaneously improve the design and reduce the time and cost of the design cycle by solving the MDO problem.

The MDO framework and architectures are developed for using numerical optimization to perform the design of systems that involve a number of subsystems or disciplines. The type of MDO architecture and optimization method has affected optimization process time and optimal design convergence (Martins and Lambe, 2013).

In the current AUV development, the engineering aspect of the design is decoupled from the development of the tactics in which the AUV is employed. Tactics are developed by intelligence experts, while AUV design is handled by engineers. If the design of AUV is simultaneously performed with the design of tactics, then a more effective AUV can be created.

Application of Multidisciplinary Design Optimization methods has been carried out in the design of an AUV: Belegundu et al. (2000)

* Corresponding author.
E-mail addresses: mohsenbidoki@aut.ac.ir (M. Bidoki), mortazavi@aut.ac.ir (M. Mortazavi), sabzeh@aut.ac.ir (M. Sabzehparvar).

https://doi.org/10.1016/j.oceaneng.2017.10.050
Received 29 November 2016; Received in revised form 16 September 2017; Accepted 22 October 2017

0029-8018/© 2017 Elsevier Ltd. All rights reserved.

developed the Collaborative Optimization (CO) method and free gradient based optimization for designing undersea exploratory vehicles. Yukish et al. (2000) surveyed requirements for improving the conceptual design of an AUV by various methods of MDO such as AAO, MDF and IDF. In McAllister et al. (2002), based on IDF architecture, an AUV was decomposed into a system module and five subsystems: guidance and control, payload, power, machinery, and hydrodynamics/propulsion and finally, payload length for exploratory electronic equipment is maximized. Fitzgerald et al. (2002) introduced The Torpedo Optimization, Analysis, and Design (TOAD) program as a parametric sizing and synthesis tool and response surface methodology was introduced as a means for the efficient modeling of different propulsion systems. Design and optimization of an undersea vehicle in three design modules: path planning, component selection and sizing, and structural analysis are performed by Benanzer et al. (2008). Multidisciplinary Design Optimization has been used for designing the guidance system of an AUV based on IDF architecture by Zhang et al. (2013).

Luo and Lyu (2015) incorporated the Collaborative Optimization (CO) as MDO framework and Particle Swarm Optimization (PSO) as optimizer to optimize hydrodynamic performances of underwater robots. All of the presented methods have only focused on the optimization design of an AUV and the engineering aspect of design was decoupled from the development of the tactics in which the AUV was employed. Frits, 2004 proposed a new paradigm of simultaneous tactics development and AUV design and looked at the implications of various tactics on the optimal design of an AUV. Finally, it was shown that if the AUV was optimized for any single tactical situation, its performance would then be sub-optimal for other tactical situations. Frits et al. have done their research in a traditional framework and they had suggested the application of a MDO framework in future works. Frits's research in the design of AUV and tactics is simultaneously a baseline in our research.

In this paper, a new efficient framework, as an innovation work, is proposed in which AUV is optimized from both engineering and tactic aspects. For achieving this goal, we have found an optimal system design by using MDO-PSO methodology in engineering space for any single tactical situation and have saved them as a local optimization database.

If off-design performance of any AUV in the local optimization database is evaluated for the entire tactical space, the performance of the AUV is changed and the off-design performance is sub-optimal with respect to locally optimized performance because the performance of any AUV in the local optimization database is not optimized for the entire tactical space.

By minimizing the difference between the locally optimized objective function and sub-optimal objective function, we could archive appropriate criterion in tactical space and finally we found the optimal design of AUV for each tactical space.

2. Literature review and background

2.1. Multidisciplinary Design Optimization (MDO)

Multidisciplinary design Optimization is a methodology that focuses on optimization methods to perform the design of systems that involve a number of subsystems or disciplines and their interactions. The design process of complex engineering systems requires mathematical formulations that contain these interactions. By solving the MDO problem, designers can simultaneously improve the design and reduce the time and cost of the design cycle.

The MDO methods in various frameworks and architectures have been dedicated to making new formulations of the optimization problem, aimed at reducing the complexity of the problem and allowing the more efficient use of traditional optimization methods.

The MDO methods have developed both on addressing how the different disciplines are coupled and how the overall optimization problem is solved. Selection of a suitable type of MDO architecture and suitable optimization method depends on the complexity of the system, the required disciplines, the computation effort, the optimal design convergence and improvement in feasibility.

The MDO architectures have been divided to monolithic (single level) and distributed (multi-level) methods (Martins and Lambe, 2013). In a monolithic approach, a single optimization problem is solved. Common monolithic methods included All At Once (AAO), Individual Discipline Feasible (IDF) and MultiDisciplinary Feasible (MDF) (Agte et al., 2010; Martins and Lambe, 2013). In a distributed approach, the same problem is partitioned into multiple subproblems containing small subsets of the variables and constraints. The distributed approach included Collaborative Optimization (CO), Bi-Level Integrated System Synthesis (BLISS) and Concurrent SubSpace Optimization (CSSO).

In this research, because of special structure of design (design optimization in tactical space), we need to satisfy the feasibility of design in any situation even though optimization process is stopped. In other words, we are not as concerned with finding an optimal design in the strict mathematical sense as with finding an improved design in the engineering sense.

Among all of MDO architectures, MDF method is the best choice as MDO architecture for this context. We choose MDF architecture because of its advantage over than the other monolithic architecture that it is: always feasible design. In other words, MDF returns a system design that always satisfies the design constraints in each iteration, even if the optimization process is terminated early. Hence, the other monolithic MDO methods do not achieve feasible design until the optimization process is complete. The difference between two approaches is shown in Fig. 1. This is advantageous in an engineering-design context if time is limited and our concern is to find an improved design that needs not be optimal in the strict mathematical sense.

In MDF architecture, the optimization problem has been as small as possible since only the design variables, objective function, and design constraints are under the direct control of the optimizer. In this architecture, a set of coupling variables must be calculated before each optimization iteration and when they return to the optimization level for evaluating the objective function and constraint. This method usually has a slow convergence rate. The slow convergence rate can be improved by an appropriate replacement of disciplines for reducing the feedback loop (return the output variables of one discipline to the other discipline in the top level). Gradient calculations are also much more difficult for MDF than for IDF and AAO, but if gradient free optimization is used as the optimizer, then this approach can simultaneously improve feasibility and optimality.

2.1.1. Formulation of Multidisciplinary Feasible (MDF)

An optimization problem in the MDF architecture can be shown as the following equation:

$$\begin{aligned} &\textbf{min} \quad \boldsymbol{f}\left(\boldsymbol{x}_0, \boldsymbol{x}_i, \boldsymbol{y}_i\left(\boldsymbol{x}_0, \boldsymbol{x}_i, \boldsymbol{y}_{j\neq i}\right)\right) \\ &\textbf{with respect to} \quad \boldsymbol{x} = [\boldsymbol{x}_0, \boldsymbol{x}_i] \\ &\textbf{subject to} \quad \boldsymbol{g}_i\left(\boldsymbol{x}_0, \boldsymbol{x}_i, \boldsymbol{y}_i\left(\boldsymbol{x}_0, \boldsymbol{x}_i, \boldsymbol{y}_{j\neq i}\right)\right), \boldsymbol{i} = 1, \ldots, \boldsymbol{N} \end{aligned} \tag{1}$$

in Eq. (1), x_0 is the vector of shared design variables, x_i are the local design variables, y_i are the discipline output variables and $f(.)$ and $g_i(.)$ are the objective function and the design constraints, respectively.

The optimizer only controls the vector of design variables (shared and local), $x = [x_0, x_i]$, $i = 1, \ldots, N$ and disciplines analyses for achieving output variables are done before each optimization iteration. The discipline analyses that describe governing equations of disciplines (D_i , $i = 1, \ldots, N$) can be given by the following equation:

$$\boldsymbol{y}_i = \boldsymbol{D}_i\left(y_{j\ (j\neq i)}, x_0\ , x_i\right) \tag{2}$$

For having a feasible design, MultiDisciplinary Analysis (MDA) block

Download English Version:

https://daneshyari.com/en/article/8063696

Download Persian Version:

https://daneshyari.com/article/8063696

Daneshyari.com