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Design and construction of an autonomous underwater vehicle

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ABSTRACT

Autonomous underwater vehicles (AUVs) are becoming increasingly popular for ocean exploration, military and industrial applications. In particular, AUVs are becoming an attractive option for underwater search and survey operations as they are inexpensive compared to manned vehicles. Previous attempts on AUV designs have focused primarily on functional designs while very little research has been directed to identify optimum designs. This paper presents an optimization framework for the design of AUVs using two state-of-the-art population based optimization algorithms, namely non-dominated sorting genetic algorithm (NSGA-II) and infeasibility driven evolutionary algorithm (IDEA). The framework is subsequently used to identify the optimal design of a torpedo-shaped AUV with an overall length of 1.3 m. The preliminary design identified through the process of optimization is further analyzed with the help of a computer-aided design tool, CATIA to generate a detailed design. The detailed design has since then been built and is currently undergoing trials. The flexibility of the proposed framework and its ability to identify optimum preliminary designs of AUVs with different sets of user requirements are also demonstrated.

1. Introduction

Autonomous underwater vehicles (AUVs) have become an interesting area of oceanic research because of their promising uses in military applications, homeland security, hydrographic surveys, mineral field surveys, environment monitoring and oceanographic studies. Over the years, there have been intensive efforts toward the development of sea-worthy AUVs to meet the challenges of oceanographic exploration and exploitation programs. Recently AUV development is focused on improving the operation range and endurance for long term data collection in the fields of oceanography and coastal management [1]. The growth of cooperative AUV application has increased the significance of optimum energy consumption of AUVs [2]. The AUV's mission is often compromised due to the on-board limited energy storage capacity. The vehicle must save energy during the period of observation to be able to cruise longer distances over a period of time. For this purpose, a body shape with low resistance is desirable [2,3]. Therefore, in the preliminary stage of AUV design, hull resistance reduction is one of the key design targets [4].

While optimization techniques have been applied successfully to a wide range of applications spanning various fields of science and engineering, there is a very limited literature on optimization of AUV designs [5]. Hydrodynamic optimization is rarely applied in the context of AUV design as existing design tools are not sufficiently robust and/or fast to be used within an optimization scheme [6]. For this reason, previous attempts on AUV designs reported in the literature have focused primarily on functional designs and non-optimal designs are often adopted and accepted as an option. As the desire/need to minimize the use of resources (e.g. fuel, building cost, and time for design) become increasingly important, optimization approaches become increasingly popular [7]. For example, Husaini et al. [2] have worked on the AUV hull design by using numerical method to reduce the drag. Yamaguchi et al. [3] have used numerical simulations based on the finite difference method to optimize the body shape of their vehicle in order to reduce the resistance. Alvarez et al. [6] have investigated the optimum hull shape of an underwater vehicle moving near the free surface using simulated annealing (SA) optimization technique while Joung et al. [8] have employed computational fluid dynamics (CFD) analysis with the same goal. Beside that, Martz and Neu [9] have developed a design optimization process for an AUV using a multiple objective genetic optimization (MOGO) algorithm.

AUV design optimization is not a new concept, but it poses difficult computational problems. The design space is often large with functions and constraints exhibiting severe nonlinearities. An *ad hoc* process for making these critical design decisions is not adequate for the design of highly integrated AUV systems. Therefore, much work still needs to be done in terms of optimizing the AUV hull form design to minimize drag and increase propulsion efficiency [8].

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While the major thrust has been on hull form optimization of AUVs, limited attention has been paid on the arrangement strategies within the hull items, i.e. how to optimally place the internal on-board components in a clash-free state while maintaining appropriate clearance among them, and other factors that affect controllability, like the centre of gravity (CG) and the centre of buoyancy (CB) effects. The term *clash-free* is defined here as the placement of the internal on-board components without an overlap and with appropriate clearance among them. AUVs use on-board computers, power packs and vehicle payloads for automatic control, navigation and guidance. Also the AUVs can be equipped with state-of-the-art scientific sensors to measure oceanic properties, or specialized biological and chemical payloads to detect marine life when in motion [10]. The small AUV, REMUS [11] which has a low internal payload volume, requires small-sized sensors. The viability of using such AUVs is largely dependent on the availability of small AUV compatible sensors [10]. The AUV should possess some free internal volume for adequate buoyancy [12]. Thus it is important to consider the internal arrangement of components on-board and their optimum placement to ensure space, weight, appropriate location of the CG and CB of the AUV, in addition to its external shape and size. These establish the need for the development of a framework that is capable of generating the optimum design of AUVs by simultaneously considering both internal clash-free arrangement of on-board components and external size and shape for a given set of design requirements.

In summary, the AUV design still poses several challenges and the aim of the present work is to identify efficient and seaworthy AUVs for a given set of user requirements. To this end, this paper focuses on the development of an optimization framework for representing various torpedo shaped AUV geometries through seamless integration of Matlab-CATIA and in-house performance analysis codes for reduced design cycle time and added flexibility. The objective is to find an appropriate hull shape to minimize drag and optimum clash-free placement of the internal objects for optimal CG–CB separation thereby ensuring better controllability of a vehicle moving submerged near the free surface while fulfilling the design constraints. Since during the phase of optimization, the components are represented as rectangular bounding boxes, the vehicle dimensions are essentially preliminary estimates. During the phase of detailed design, the orientation of the objects and their actual geometry are considered and modified. The final design is then built to resolve remaining uncertainties in the design process.

The rest of the paper is organized as follows. The proposed optimization framework is described in Section 2. In Section 3, the details of the numerical experiments are given, followed by a discussion of results (optimum designs) obtained. Finally, the findings of this study are summarized in Section 5.

2. Optimization framework

This work presents an optimization framework for the design of AUVs based on the given design requirements. The framework incorporates a geometry and configuration modules, a hydrodynamics module, several accepted maritime performance and characteristics estimation methods of AUVs and a suite of optimization algorithms. The design optimization process starts with the initialization of a set of solutions. Such solutions are randomly generated using the variable bounds and fed into the geometry and configuration modules. The geometry and configuration modules generate a design for each of these solutions using the catalogue information which in turn translates to a hull form geometry and location of the components. These modules not only generate the external hull geometry but also place the internal on-board components in a clash-free state. Once the internal parts are placed in a clash-free state, the parallel mid-body geometry is generated to cover the internal arrangement, and then the nose and tail cone geometries are coupled along with the mid-body, thereby generating the complete vehicle geometry. The performance of the candidate design is then evaluated. The optimization process runs till the assigned number of function (design) evaluations is completed. The optimization process has an option to visualize every candidate design. The detailed flowchart of the optimization framework is presented in Fig. 1 with further discussion of its components in the subsequent sections.

The framework consists of five applications namely Matlab, CATIA, Microsoft Excel, Text Document and VBScript. Matlab is used for numerical computation/optimization. CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform computer-aided design (CAD) software tool used to model and visualize candidate designs. Microsoft Excel and Text Document are used as a medium of communication between applications. VBScript (Visual Basic Scripting Edition) is used for CATIA automation wherein the 3D model of the candidate design can be generated without user intervention. Fig. 2 shows a generic sequence diagram to illustrate the work flow.

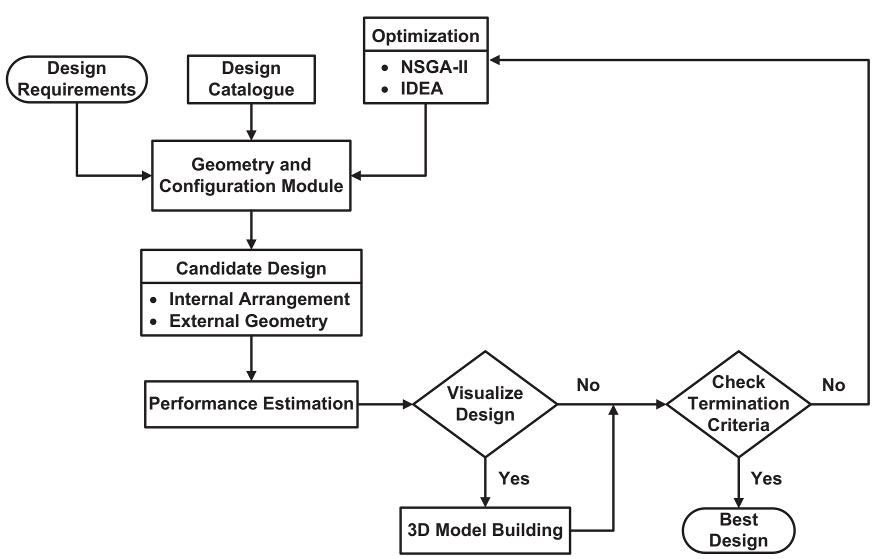

Fig. 1. Detailed flowchart of the optimization framework.