**ΕΘΝΙΚΟ
ΜΕΤΣΟΒΙΟ
ΠΟΛΥΤΕΧΝΕΙΟ**
ΣΧΟΛΗ ΜΗΧΑΝΟΛΟΓΩΝ ΜΗΧΑΝΙΚΩΝ

ΚΟΣΜΗΤΟΡΑΣ

Α.Π. : 43909
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**Προς τα Μέλη ΔΕΠ της
Σχολής Μηχ/γων
Μηχ/κών**

ΠΡΟΣΚΛΗΣΗ

Σας προσκαλούμε στην παρουσίαση της Διδακτορικής Διατριβής του Υ.Δ. **κ. Καψούλη Δημήτριου του Ηλία** , διπλωματούχου Μηχανολόγου Μηχανικού του ΕΜΠ, την οποία εκπόνησε στον Τομέα **Ρευστών**. Η παρουσίαση θα πραγματοποιηθεί την *Τετάρτη 25 Σεπτεμβρίου 2019*, *ώρα 13:00 το μεσημέρι στην αίθουσα Πολυμέσων στο κτίριο της Κεντρικής Βιβλιοθήκης ΕΜΠ* - Πολυτεχνειούπολη Ζωγράφου. Ο ελληνικός τίτλος της Διδακτορικής Διατριβής είναι ο εξής :

«ΕΞΕΛΙΚΤΙΚΟΙ ΑΛΓΟΡΙΘΜΟΙ ΧΑΜΗΛΟΥ ΚΟΣΤΟΥΣ ΥΠΟΒΟΗΘΟΥΜΕΝΟΙ ΑΠΟ ΜΕΤΑΠΡΟΤΥΠΑ ΚΑΙ ΕΦΑΡΜΟΓΕΣ ΤΟΥΣ ΣΤΗ ΒΕΛΤΙΣΤΟΠΟΙΗΣΗ ΜΟΡΦΗΣ ΣΤΗ ΡΕΥΣΤΟΔΥΝΑΜΙΚΗ»

και ο Αγγλικός Τίτλος ως εξής:

«LOW-COST METAMODEL-ASSISTED EVOLUTIONARY ALGORITHMS WITH APPLICATION IN SHAPE OPTIMIZATION IN FLUID DYNAMICS »

Ο Κοσμήτορας της Σχολής

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Low-Cost Metamodel-Assisted Evolutionary Algorithms with Application in Shape Optimization in Fluid Dynamics

Εξελικτικοί Αλγόριθμοι Χαμηλού Κόστους Υποβοηθούμενοι από Μεταπρότυπα και Εφαρμογές τους στη Βελτιστοποίηση Μορφής στη Ρευστοδυναμική

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PhD Thesis Abstract

The scope of this PhD is to propose, develop and assess several upgrades to existing shape optimization methods based on Evolutionary Algorithms (EAs). The efficiency of the proposed improvements is demonstrated in a number of real-world applications in the field of fluid mechanics (aerodynamic, hydrodynamics and turbomachinery) which are associated with computationally expensive evaluation software. They noticeably reduce the computational cost of optimization compared to the available (background) methods, which are still based on EAs enhanced by metamodels (Metamodel-Assisted EAs or MAEAs) and distributed search. Metamodels, mainly Radial Basis Function networks, are on-line trained personalized surrogate evaluation models, meaning that a local metamodel is trained for the pre-evaluation of each new individual generated during the evolution. This is in contrast to the common use of off-line trained metamodels widely used by other relevant methods. Parallelization, in the form of concurrent evaluations of the candidate solutions on the multi-processor platform of the Parallel CFD \& Optimization Unit (PCOpt) of the Lab of Thermal Turbomachines of the NTUA is an indispensable feature of the proposed method variants. All developments have been made in the generic optimization platform EASY (Evolutionary Algorithm SYstem) developed by the PCOpt/NTUA. In all but one optimization problems, the problem-specific model to evaluate the candidate solutions is the GPU-enabled CFD solver PUMA developed by the same group. Only in the case of the optimization of the valveless diaphragm micropump, a different in-house CFD tool based on the cut-cell method is used instead.

The most important contributions of this thesis are listed below:

a) The use of Principal Component Analysis (PCA) to assist the EAs during the evolution. In this thesis, the Kernel PCA is used and is shown to provide better results compared to the Linear PCA used so far. In each generation of the EA, the PCA performs an eigendecomposion of the offspring population. The resulting eigenvectors define a new feature space, which the population members are transformed into; the evolution operators are applied in the feature space in which they perform optimally. Moreover, the PCA assists the MAEAs. Metamodels are only trained on the most important variables (directions in the feature space) indicated by the PCA, while the rest are safely truncated, as these generate noise at the predictions. The metamodels are trained with transformed by the PCA patterns, with truncated design variables, leading to reduced training cost and more dependable predictions. The two-fold usage of PCA drives the EA-based search in a much better way.

b) A PCA-based Hybrid Algorithm aiming at maximum efficiency in Multi-Objective Optimization (MOO). This hybrid method combines the advantages of EA and Gradient-Based (GB) optimization. The EA explores the design space while the GB method regularly upgrades the most promising solutions. The required gradients of the objective functions with respect to the design variables are efficiently computed with the continuous adjoint method developed and programmed in the PCOpt/NTUA, at a cost which is independent of the number of design variables. In MOO, the direction along which the GB method updates the selected individuals is of outmost importance. Herein, the Linear PCA computes the principal components of the objective space by processing the objective function values of individuals forming the current front of non-dominated solutions. The principal component (direction) corresponding to the minimum variance is perpendicular to the current front and points towards the direction of the simultaneous improvement of all objective functions, so this is used for the GB refinement. The proposed hybrid method performs better than the non-hybridized EA-based search.

c) Multi-Criteria Decision Making (MCDM) within EAs to account for the Decision Maker's (DM) preferences during the evolution. In contrast to standard multi-objective EAs which may insufficiently populate the preferred area(s) of the objective space, more non-dominated solutions are now driven towards them. This is achieved by using the MCDM Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), which affects the parent selection and the non-dominated front trimming operators.

d) Flow prediction with Deep Neural Networks (DNNs) to assist the design/optimization of aerodynamic shapes. Trained on databases of CFD simulations, DNNs learn to predict the flow field around/inside these bodies, such as airfoils, wings and turbomachinery cascades. In this thesis, inputs and outputs are processed as images, in 2D cases, or raw data, in 3D cases. The DNNs are validated on new shapes and their ability to replicate the CFD results with high precision and low computational cost is demonstrated. The DNNs are employed as off-line trained metamodels during the EA-based search, in contrast to the on-line trained metamodels used in the aforementioned MAEAs.

The background and the aforementioned methods can work synergistically or separately to improve the performance of EA-based optimization methods as it is demonstrated in two groups of CFD applications. The first group consists of some "standard" CFD-based optimization problems, the so-called benchmark cases. Each time a new variant is presented, these are revisited. By doing so, the reader should clearly assess the improvement offered by the proposed method. In a separate chapter of this thesis, a number of industrial cases are presented and optimized with the most efficient methods presented. These include the shape optimization of: (a) an Aircraft Wing-Body Configuration, (b) the DrivAer Car, (c) an Ultra-light Aircraft, (d) a Francis Runner and (e) a Valveless Diaphragm Micropump.

Keywords: Evolutionary Algorithms, Multi-Objective Optimization, Metamodels, Kernel Principal Component Analysis, Hybrid Optimization, Multi-Criteria Decision Making, Gradient-Based Optimization, Deep Neural Networks, Computational Fluid Dynamics.

Athens, 2019