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ACCELERATING AERODYNAMIC SHAPE DESIGN USING METAMODEL-ASSISTED PARTICLE SWARM OPTIMIZATION

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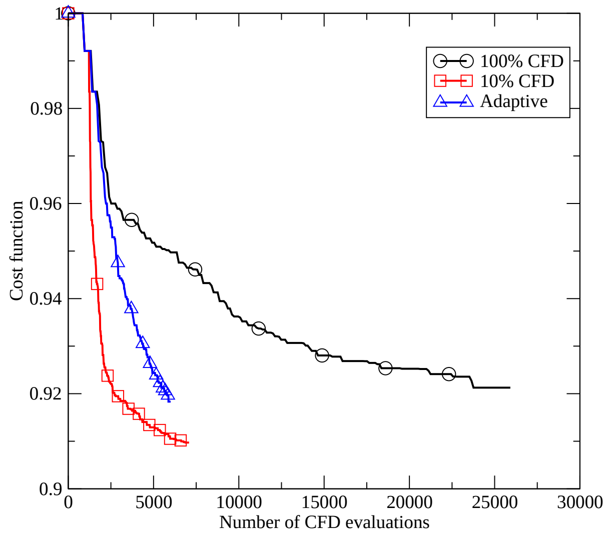
ABSTRACT

Particle Swarm Optimization (PSO) [1] has emerged as a very robust tool for solving practical optimization problems. Compared to evolutionary algorithms, PSO has smaller number of parameters and usually converges faster. However it still requires a large number of function evaluations in order to reliably locate an optimum solution. With the increasing use of high fidelity analysis tools (like CFD) in optimization, the cost of one function evaluation can be rather high. In the case of evolutionary algorithms this problem has been solved to some extent by the use of metamodels (also called surrogate models). A metamodel (literally, a model of a model) provides a cheaper alternative to the expensive function. The most commonly used type of metamodels are function approximations like response surfaces, neural networks, radial basis functions (RBF) and kriging. Due to their ability to model highly non-linear multi-dimensional functions using sparse datasets, RBF and kriging have emerged as the preferred tool for metamodel-assisted optimization.

The high dimensionality and complex function landscapes encountered in practical design problems precludes the use of global metamodels. Global approximations are also costly to construct; this is particularly so due to the need to iteratively update the model as new function values are obtained during the optimization process. Local metamodels on the other hand can be constructed easily and cheaply, and can better model the complicated functions encountered in engineering design. Giannakoglou et al. [2] have proposed a two-level evaluation strategy, called Inexact Pre-Evaluation (IPE), to reduce the computational time related to GAs. It relies on the observation that numerous cost function evaluations are useless, since numerous individuals do not survive to the selection operator. Hence, it is not necessary to determine their fitness accurately. The strategy proposed by Giannakoglou consists in using local metamodels to pre-evaluate the fitness of the individuals in the population. Then only a small portion of the population which corresponds to the most promising individuals are selected (pre-screening) and accurately evaluated using the original and expensive model.

Inspired by the success of GAs combined with metamodels and IPE, we study the application of a similar strategy to particle swarm optimization. Like genetic algorithms, PSO is also a rank-based algorithm; the actual magnitude of cost function of each particle is not important but only their relative



	Cost	CFD eval	Iter
Initial	1.0	-	-
100% CFD	0.9212	25920	216
10% CFD	0.9097	7080	500
Adaptive	0.9183	6002	500

Figure 1: Results of PSO (120 particles) for supersonic business jet

ordering matters. An examination of the PSO algorithm shows that the main driving factors are the local and global memories. Most of the cost functions are discarded except when it improves the local memory of the particle. Hence in the context of PSO also, an inexact pre-evaluation strategy seems to be advantageous in identifying promising particles, i.e., particles whose local memory is expected to improve, which can then be evaluated on the exact function. We thus propose a metamodel-assisted PSO with inexact pre-evaluation together with a new pre-screening criterion which is specific to PSO. This criterion has the potential to be adaptive in the sense that the number of exact evaluations is automatically determined. We also test a criterion based on ranking the particles after the pre-evaluation and selecting a specified percentage of best particles for exact evaluation.

The proposed algorithm is implemented in our multi-strategy and multi-level optimization platform called FAMOSA. Local metamodels are constructed using radial basis functions; the attenuation factor which is a parameter in the RBF is selected using leave-one-out technique. The algorithm is applied to the inviscid aerodynamic shape optimization of a supersonic business jet and a transonic wing. The optimization involves minimizing the drag under constraints of lift and geometry using penalty functions, and the shape deformation is parameterized using free-form deformation with 20 parameters. Figure and table (1) show the reduction in cost function achieved with different methods for the supersonic business jet. Both the pre-screening criteria are able to reduce the cost function to the same level as in the case of exact evaluations alone, while the number of costly function evaluations are reduced by 70%. In fact with metamodels, it is possible to obtain better solutions due to the ability to perform more iterations (hence greater exploration of design space) without substantial increase in computational cost. In both test cases considered, the proposed metamodel-assisted PSO was able to achieve considerable reduction in the number of CFD evaluations while finding optimal shapes that are as good as in the case of CFD evaluations alone.

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