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The development and application of tailored test problems for meta-simulation of multidisciplinary optimization of vehicle structures

Ramses Sala[1]*, Marco Pierini[2] and Niccolò Baldanzini[3]

[1] Università degli Studi di Firenze, Via di Santa Marta 3, 50139 Firenze Italy, ramses.sala@unifi.it
[2] marco.pierini@unifi.it
[3] niccolo.baldanzini@unifi.it

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In the last decades a tremendous amount of biologically inspired metaheuristic optimization algorithms have been developed [1]. The application of such optimization methods is widely spread in various fields of engineering, including those dealing with single or multidisciplinary design optimization (MDO) based on numerical simulation responses, from disciplines such as crashworthiness and structural dynamics for automotive applications [2]. For optimization-practitioners from the field of engineering that deal with complex computationally expensive simulation responses, there is only few literature available that contains statistically significant performance comparisons, or guidelines regarding the efficiency of optimization algorithms for common but specialistic application types. It is an unsatisfactory situation that problem types for which there is an high interest in increased optimization efficiency, are also the problem types for which few information is available regarding optimization performance and efficiency. Several sources identified this problem [3,4] and the need for statistically significant performance comparisons and the development of benchmark, and test problems have been addressed. There is quite a variety of test problems available for theoretical performance analysis and experimental performance analysis of optimization algorithms and architectures. Examples of such test functions or artificial landscapes are the Rosenbrock function and the Rastrigin function for single objective optimization and the ZDT functions [5] for multi objective optimization. For many practitioners it remains however difficult to relate such test functions to a particular application type or vice versa. This is especially the case for multidisciplinary optimization applications for which the disciplines of interest have dissimilar structures, and various types of interdisciplinary couplings exist.

The objective of this work is to characterize simulation responses and their couplings of a particular set of disciplines related to MDO of vehicle structures, in order to develop test problem functions that are computationally inexpensive to evaluate and that have representative response structure for these type of objectives. The developed test functions enable to compare and select efficient optimization algorithms for particular problem types. Furthermore the test problems enable tuning of the optimization algorithm meta-parameter settings to increase the optimization efficiency further.

For several vehicle models the responses of crashworthiness criteria (such as peak acceleration, intrusion and deformation), and vibrational comfort criteria (such as. global natural frequencies) are investigated. For each response type, typical features are characterized using various parameter studies, global sensitivity analysis and metamodeling methods, such as High Dimensional Model Representation (HDMR) and smoothing spline Analysis of Variance (SS-ANOVA). Also several types of coupling between the different responses have been investigated and quantified. The characterization results are used to formulate and calibrate a set of test functions aiming to have a similar and representative structure with respect to the simulation responses. The test problem functions are used to compare several optimization algorithms, and tune algorithm parameters. The obtained algorithm performance comparison results, and tuned meta-parameter settings are corroborated using optimizations on several vehicle model simulation workflows. The results show a good qualitative and quantitative resemblance between the optimization algorithm performances on real vehicle model simulations and the developed test functions. Using the test functions for algorithm selection and tuning of the optimization algorithm meta-parameters resulted in absolute performance increases of 10-20%, and relative performance increases over 70% with respect to optimization results obtained using common general purpose optimization parameter settings.

Further refinements and generalizations of the test problem function formulations are in progress, but already in their present form a significant effectiveness for the investigated application is demonstrated. Although the approach is now applied to particular responses from crashworthiness and structural dynamics, the idea can be applied to applications in other disciplines in engineering or to optimization problems in other fields that deal with a limited function evaluation budget. The results could motivate other researchers and developers to apply, or modify the presented function formulation for their particular purposes, or to adopt the conceptual idea of application derived test problem functions. Such application based test problem functions contribute to meet the criteria for experimental analysis of algorithms stated in [6] in terms of, statistically significant performance quantification, reproducibility, and comparability. As an outlook: such test functions could also be used for a more detailed meta-simulation and optimization of the optimization process, in order to select and achieve an efficient combination of: the problem formulation, optimization algorithms, algorithm settings, and simulation resource allocation, to increase the optimization performance further.

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