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PARALLEL SIMULATION OF FLUID-STRUCTURE INTERACTIONS WITH ACOUSTIC FLUIDS

Miriam Mehl[1], Bernhard Gatzhammer[2] and Benjamin Uekermann[3]

[1] Institute for Parallel and Distributed Systems, Universität Stuttgart, Universitätsstraße 38, 70569 Stuttgart, miriam.mehl@ipvs.uni-stuttgart.de, http://www.ipvs.uni-stuttgart.de/abteilungen/sgs/
[2] Department of Computer Science, Technische Universität München, Boltzmannstraße 3, 85748 Garching, gatzhamm@in.tum.de, www5.in.tum.de
[3] Institute for Advanced Study, Technische Universität München, Lichtenbergstraße 2a, 85748 Garching, uekerman@in.tum.de, www5.in.tum.de

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Whithin the last years, many great numerical achievements have fostered the simulation of multi-physics scenarios using partitioned approaches treating the involved physical fields with independent, established and trusted solvers that are glued together with a coupling tool. Even for hard problems such as fluid-structure interactions with incompressible fluids and lightweight and flexible structures, stable and fastly converging solvers have been developed. Among the most efficient methods that come along with only a handful of fluid- and structure solvers per implicitly coupled time step of a fluid-structure system, is the interface quasi-Newton method presented, e.g., in [1] based on previous work in [2]. For the simulation of fluid-structure interactions involving turbulent and acoustic fluids, we have to apply these methods to systems with very high grid resolution that, thus, have to be simulated on massively parallel supercomputing architectures. In this context, a drawback of the commonly used coupling methods becomes evident: the iterations within a time step typically are done in a staggered way, i.e., a fluid solve is followed by a structure solve and so forth. Therefore, our overall scalability deteriorates if one of the solvers (typically the structure solver) is much cheaper and can be executed only on a comparably small number of cores. Changing the execution order requires the development and analysis of new methods. For this purpose, we decomposed the approved interface quasi-Newton method into its two parts, a fixed-point equation and a fixed-point equation solver. As the fluid solver uses displacements and velocities as an input and computes forces exterted on the structure as an output, whereas the structure solver takes these forces and computes displacements and velocities, convergence of the iteration is achieved if the input of the overall iteration equals the output [1]. This corresponds to the fixed point equation (S-

[1] With this, we have fulfilled the two coupling conditoions for viscous fluids: equality of forces and

FPE) $S \circ F(d) = d$ where S and F denote the structure and flow solver, d summarizes displacements and velocities at the interface between fluid and structure. If we want to execute both solvers simultaneously, we have two basic possibilities: use the same input-output relation for both and translate the output difference into a correction of the input or use different input-output relations for flow and structure solver auch that the output of one solver becomes he input of the other as in the standard approachvshown above. This corresponds to the two fixed-point equations

$$d + S^{-1}(d) - F(d) = d \quad \text{and} \quad \begin{pmatrix} 0 & F \\ S & 0 \end{pmatrix} \begin{pmatrix} f \\ d \end{pmatrix} 0 \begin{pmatrix} f \\ d \end{pmatrix}$$

where S^{-1} denotes a structure solver using displacements and velocities as an input and yielding forces as an output. We call the first equation the parallel fixed-point equation (P-FPE) and the second one the the vectorial fixed-point equation (V-FPE). As described in [3], the P-FPE can not be solved with a simple fixed-point iteration. For the V-FPE, it can be easily shown that a simple fixed-point iteration as a solver is equivalent to two independent instances of fixed-point iterations for the original S-FPE which doubles the work and, thus, prevents us from profiting from the increased parallelism. However, we can combine both equations with an interface quasi-Newton approach executing a fixed point iteration step $\tilde{x}_i = H(x_i)$ for an equation $x = H(x)$ followed by a quasi-Newton step based on a least-squares solver minimizing the residual of the new iterate $x_{i+1} := \tilde{x}_i + \sum_{j=1}^{i} \alpha_j \Delta\tilde{x}_j$ with $\Delta\tilde{x}_j := \tilde{x}_j - \tilde{x}_{j-1}$ and

$$(\alpha_j)_{j=1,\dots,i} \quad := \quad \operatorname{argmin} \left\| r_i + \sum_{j=1}^{i} \alpha_j \Delta r_j \right\| \quad \text{with} \quad \Delta r_j = H(x_j) - x_j - H(x_{j-1}) + x_{j-1}$$

under the assumption that H can be locally approximated by a linear mapping. With this, both P-FPE and V-FPE can be solved with a number of iteration that is comparable to that needed to solve the S-FPE. We demonstrate this for a collection of benchmark examples and show scalability results for different spatial resolutions and different numbers of processors. It turns out that the scalability is still limited by the non-simultaneous execution of solver steps and coupling numerics which is the next issue to be solved.

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equality of displacements/velocities.