sense
Fluid Simulation Toolbox

SENSE – Affordable CFD simulation software for SMEs in the transportation industry

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1. Introduction

Small Medium Enterprises (SMEs) are facing the new challenges presented by Industry 4.0 and in many cases they struggle with acquiring the sufficient resources for product development. Many of these companies would benefit from computational fluid dynamics (CFD) simulations software for improved product development. Use of such tools significantly reduces the prototyping costs due to the fact that major design flaws are corrected before the prototypes are even build. Unfortunately, currently available CFD simulation tools require expensive computer clusters, very long computation times and cannot be performed without a skilled simulation expert. This means that such software is out of reach for most SMEs. Since SMEs have a significant share of European as well as global markets, we decided to produce a CFD solution tailored to the needs of SMEs. Our software product 'SENSE' will not only address the applications that can already be solved by current tools but also resolve problems that are extremely difficult for standard CFD solutions. SENSE will be a disruptive element on the market of fluid simulation. Our innovative idea is to use particle based methods, which have superior performance in selected applications compared to the standard grid based CFD tools. While standard CFD solvers require extensive preparation of the computational mesh and computer clusters to run, our method does not require any pre-processing and can be run on a single workstation. SENSE will enable SMEs to perform all development and innovation activities in a reasonable time on a workstation using current staff while achieving better simulation results on R&D projects. After market deployment, this new software will become an essential instrument for SMEs, meaning that they will be able to increase their global competitiveness and enable the faster and easier acquisitions of customers.

We already identified three different topics in our development, which we did not find so far in any paper. The goal was to first identify which of those topics can be applied as patent and second apply for at least one if allowed. The ideas are:

- Toolbox consisting of modules of particle based methods suitable for users to execute the simulation with low effort.
- A new interface for particle based methods which allows the software to perform in an optimal way on different devises.
- A special particle generation method, which is very fast and in addition reduces the total memory needed for the computation drastically.

2. Sense Project

2.1. The method of hidden wall particles having no influence on results

Typically, in particle-based CFD methods, both fluid and boundaries are represented by particles. In many methods, the only difference between these two types of particles is the lack of advection of the boundary particles. In some configurations, the number of liquid particles is small or similar compared to the wall particles. Moreover, there are many situations in which the domain is only partially filled with the fluid particles. Since, usually, particles interact only with neighbouring particles which are not further then a given distance (smoothing range), the wall particles located further then this distance from any fluid particles have no impact on the result. Therefore, we proposed the idea, in which we detect such a situation and do not perform any calculation for such wall particles. To improve the efficiency of the proposed method of hiding wall particles which have no impact on the results, we decided to use the artificial regular mesh of the cell-edge size equal to the range of interaction (typical mesh used in particle based method to improve the efficiency of the local neighbour's detection). Particles in cells which do not contain fluid particles and have no neighbouring cells containing fluid particles are not included in calculation. The exemplary case is presented in Figure 1. The black and purple particles represent respectively fluid and solid (wall) particles. The particles are located on the regular grid of edge size equal to the smoothing range of kernel (circle). Green cells denote cells located not further than smoothing range from the closest fluid particle. Solid particles located in white cells has no influence on the result.

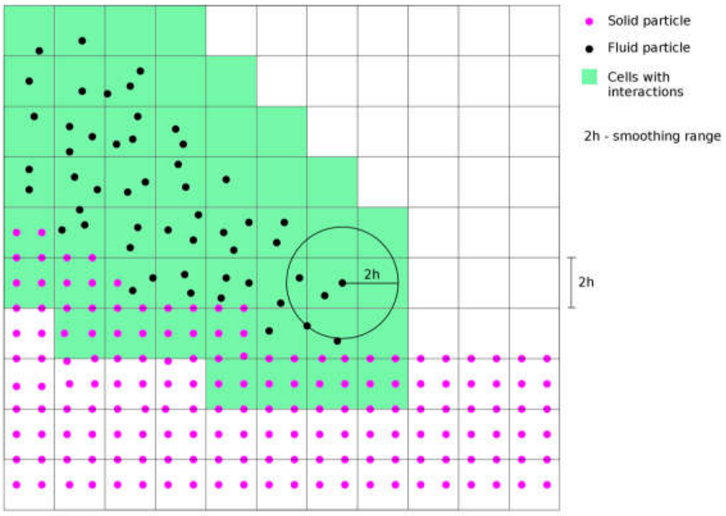

Figure 1. The idea of hiding wall particles having no influence on results.

2.2. Module based CFD Software

One big drawback of existing CFD tools is that they are highly complex. The reason is that they are versatile and cover a wide range of applications. Due to this, people need to be trained to be able to use them and the time to setup a new simulation is quite high. Our goal is to minimize the necessary training and the time to setup a new simulation. We do this through specialization. This means, that we reduce the functionalities of the software until it is only usable for one specific simulation (e.g.: Dip paint simulation, rain simulation, sloshing simulation), see Figure 2. This allows predefining most of the boundary conditions and simplifying the functionalities to an absolute minimum which consequently reduces the time necessary to setup a new simulation and reduces the necessary training to be able to use the software. We call such software "module".

An additional advantage of such a module is, that the solver and the numeric behind it can be fitted to the very problem to module is designed for which leads to increased performance and stability. The drawback of this approach is, obviously, the loss of versatility. To counter this, we need a module for every application. A set of these modules is what we call a "toolbox", see Figure 3. Every customer can put together their own toolbox according to their needs which allows fair pricing for the functionalities the customers actually need.

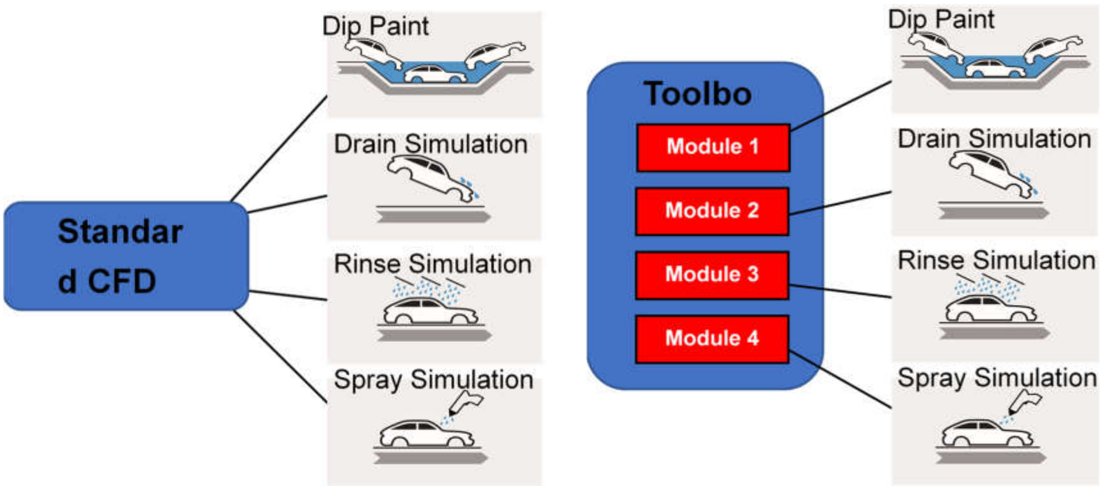

Figure 2. Difference between standard CFD tool and the module based CFD toolbox.

As an example, let us assume customer A needs 4 modules and customer B 3 modules to cover their needs and let us assume one module costs 5000€. Usually, for existing CFD Software, both customers have to buy or rent a license for the whole software for the same amount of money independent of how much they use of it. In our module based concept, the toolbox costs 20000€ for customer A and 15000€ for customer B.

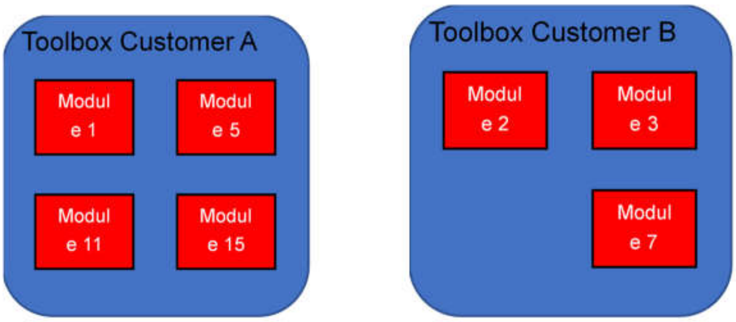

Figure 3. The exemplary toolbox configurations for different customers.

2.3.Hybrid SPH-LBM

The main problem when simulating complex fluid flows is the compromise between accuracy and the time of simulation. Especially when it comes to product optimization, simulation times highly influence the time required for product design. Existing commercial CFD software is mainly based on conventional methods, however, as described in the introductory sections these methods are often too expensive to work with, as they require a lot of time and effort to generate reliable results. Therefore there is a need for designing new CFD methods that can simulate the complex flows more accurately and more efficiently. Commonly used CFD approaches to model multi-phase flows, such as the Volume Of Fluid method (VOF) and the Level-Set method (LS), often deal with numerical diffusion across the interface and large computation clusters are required to produce any reliable results. Another problem with these methods is the fact that they are grid based, which makes it difficult to deal with complex geometries. During the last several decades a new group of CFD methods emerged; the particle methods. The most common example of these methods are Smoothed Particle Hydrodynamics (SPH), representing fluids by a set of discrete particles. Its natural ability to simulate free-surfaces and interfaces makes SPH well suitable to model multi-phase flows and complex geometries. Another group of methods that evolved are the Lattice Boltzmann Methods (LBM). The particular nature and locality of the calculations make LBM a powerful tool for modelling complex flow phenomena, including flow turbulence and multi-phase flows. The main disadvantage of the SPH method over other approaches is a high numerical cost, therefore modelling of high velocity flows e.g. gas in pipes is not very effective. However, LBM is a perfect tool to model this kind of problems. On the other side, the LBM method presents some problems in modelling fluid-flows with high density ratios, e.g. liquid-gas flows with interfaces. The SPH method is very good tool for modelling this type of problems. In order to compensate the disadvantages of both methods, we decided to create a hybrid between SPH and LBM method. In the case of multiphase liquid-gas fluid-flows, the liquid phases are simulated by the SPH method. The gaseous phases are modelled using the LBM approach. During calculation of forces acting on SPH particles, we consider also pressure at virtual particles created at the nodes of LBM solver. When solving LBM solver, the SPH particles designate the boundary condition.

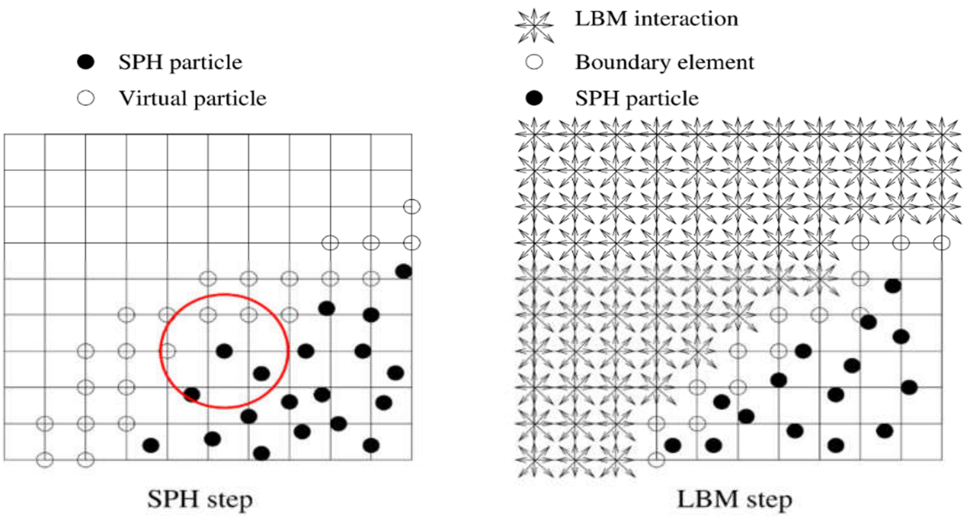

Figure 4. The hybrid SPH-LBM scheme.

3. Outcome of Patent application

We were unable to acquire all three patents under different reasons. Here we state the reasons as presented to us by the patent application office.

3.1. The method of hidden wall particles has no influence on results

The core of the idea is to include or filter only those particles into the simulation based on a grid, which have an actual influence on the currently calculated result. More specifically, only those cells of the grid which contain a fluid particle or for which at least one such fluid particle is contained in one of the adjacent cells should be calculated.

On the one hand, from our point of view, it is difficult to argue why it is not obvious for a person skilled in the art to calculate only those cells in which interactions between fluid or fluid particles and wall particles can actually occur, on the other hand it is a purely mathematical one optimization methods.

The optimization procedure on its own or on the level of abstraction you have shown is therefore in all likelihood not protected

3.2. Module based CFD software

The modularization of software is a common approach to reducing complexity. The skilled person would have no difficulty applying this universal principle in the field of CFD. It is questionable which specific aspects of modularisation are used in your case. Which components does a module contain? Are these merely framework conditions for the simulation (mathematical models) or do these modules also contain additional technical features (previously only Time step - fluid properties, maximum speeds; Convergence; Smoothing Radius - talking about mesh dialing)? Are special measures necessary if several modules are combined or is this even possible?

Without these details, an examiner will deny the novelty of the invention based on the above reasoning.

3.3. Hybrid SPH-LBM

In this method for the solution of partial differential equations (mathematical method - this even a supreme court decision) come two different algorithms, SPH for large density differences with the disadvantage of high maturity and LBM preferably in the air phase used, both known for themselves, not new are. As a pure mathematical method, the combination of both methods is not protected. Only their technical application would be protectable, if this results in additional technical features, such as a particularly optimized distribution of the simulation data on computational nodes, an efficient change between the
both methods, if they are carried out iteratively, etc.

Without a combination of the individual aspects, we see from today's point of view and based on the level of abstraction of the information you provide (the new description does not provide any new technical details) no way to meaningfully register a legal right. Usually, however, difficulties arise in the development phase, that is to say precisely in the transition from a pure intellectual model to a concrete technical implementation, the overcoming of which leads to technical features which can be placed under protection. We therefore propose to wait for this phase of development or to incorporate the first development results and prototypes into the planning of the application for protection.

4. Future steps to take

We propose to combine the individual components into an overall system for which an innovative application may be made credible, because a synergetic overall effect results (the favourable and simple simulation), which goes beyond the sum of the individual effects. For this we have made the following rough feature breakdown:

1. A method for fluid dynamic simulation of fluid particles within a simulation environment

2. For the simulation environment from several predefined simulation parameters (Time step - fluid properties, maximum speeds, convergence, smoothing radius - for grid selection) and boundary conditions, a simulation configuration can be selected,

3. The simulation domain is divided into several individual simulation cells,

3.1. The fluid particles of a simulation cell interact only with fluid particles of an adjacent simulation cell,

4. After which a simulation is carried out in parallel on several simulation devices for those simulation cells (Stokes - particle methods for the solution of partial differential equation, Smoothed Particle Hydrodynamics (SPH) works well with large density differences - for the fluid phase, but SPH is very slow, LBM in the air phase)

4.1. which there are fluid particles or

4.2. which adjoint simulation cells with fluid particles.

5. Conclusions

We applied for three patents for the SENSE software and received a negative response as explained in Section 3. However, we plan to apply again by combining all three rejected patents into one tool following the advice of the patent office.

Although, the Lattice-Boltzmann Method was not proposed in the SENSE project, we dim this methodology and combination as a bottleneck for the industry. This will be further developed and finalized future patent application.