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Deforming-Domain Problems Related to Packaging Machines: Mesh-Update Method and Flow Simulation

Fabian Key[1]* and Stefanie Elgeti[1]

Micro Abstract
We will present an efficient and accurate interface-tracking method that describes computational domains composed of a fixed and a moving component in relative translational motion. The periodic character of the motion is reflected in the method via a closed virtual ring. We will conclude with validation results as well as a simulation of the flow and temperature field inside a generic geometry of a packaging machine.

[1]Chair for Computational Analysis of Technical Systems (CATS), RWTH Aachen University, Aachen, Germany
***Corresponding author**: key@cats.rwth-aachen.de

Introduction

As part of the analysis of fluid flow problems, we often encounter situations in which we have to deal with deforming domains. These can either be due to movement of outer boundaries or internal interfaces. An example is the simulation of packaging machines. We sketched a generic setup in Figure 1.

Problems including moving boundaries or interfaces impose special requirements on the numerical methods to model the involved motion with respect to both the computational mesh and the solution field. Commonly, a distinction is made between interface capturing and interface tracking methods [2]. In the former approach, one employs an implicit description of the dynamic boundary or interface, which leads to a flexible, yet not quite accurate representation.
The class of interface tracking methods is based on boundary-conforming meshes. This requires an update of the computational mesh to account for the moving boundary. There exist several strategies to modify the mesh according to the change in the position of the interface. These strategies adjust the position of interior nodes based on the prescribed movement of the boundary nodes. As compared to remeshing, this approach is both less costly and more accurate. A method that, in addition, even allows for topological changes is the Shear-Slip Mesh Update Method

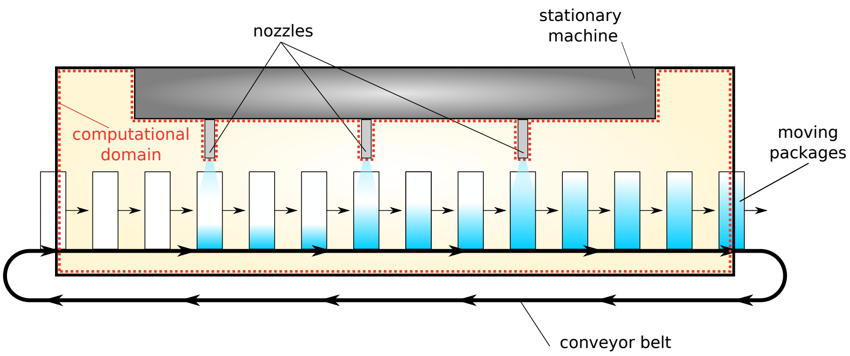


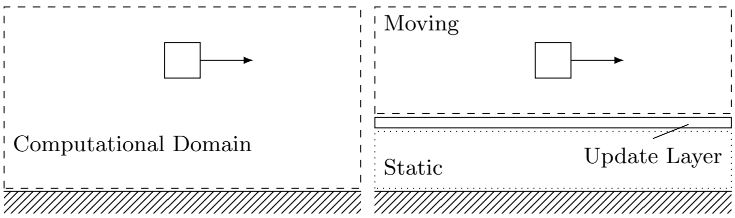
Figure 1. Sketch of a simplified packaging machine.

(SSMUM) [1]. It is applicable to rotational and translational movement. Here, only elements in a small portion of the mesh are deformed and remeshed by means of a connectivity update which also circumvents a projection of the solution field and reduces the effort of mutating the mesh.

Based on the SSMUM, we will present a novel method that allows to efficiently and accurately handle moving boundary problems. We developed an interface tracking approach that is embedded in the Deforming-Spatial Domain/Stabilized Space-Time (DSD/SST) finite element framework [3]. Its main idea is to map the translational movement in the physical domain to a continuous circular movement in an abstract space, i.e., along a virtual ring. Therefore, we will refer to it as the Virtual Ring Shear-Slip Mesh Update Method (VR-SSMUM).

1 The Virtual Ring Shear-Slip Mesh Update Method

In the following, we will focus on the modeling of domain deformations that are on the one hand strictly translational, prescribed and periodic in nature and on the other hand affect only a portion of the domain boundary, thus leading to large relative movement. The Shear-Slip Mesh Update Method (SSMUM) has been developed for this kind of problems including large but regular boundary displacements. The applications we have in mind require the use of unstructured grids due to their complex geometry and also include object entry and exit by the virtue of the periodic movement. As an example, this could be the simulation of processes which include the movement of a conveyor belt through a stationary machine casing as present in packaging machines or coating procedures. Thus, we present the VR-SSMUM which is an extension of the SSMUM and is applicable to the class of problems including translational movement as described above. The main benefits of the SSMUM, namely no need for neither global remeshing nor projection of the solution, are inherited. This implies the favorable properties of the method with respect to efficiency and accuracy.

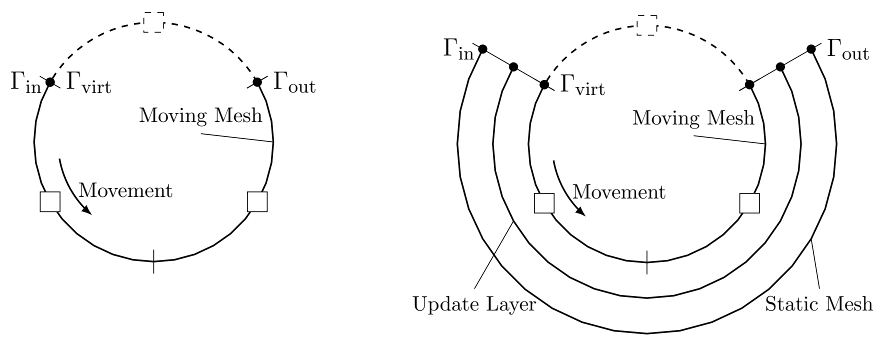


(a) **(b)**

Figure 2. Two objects in relative motion: the square undergoes an unidirectional translation, whereas the wall does not move. (a) Computational domain. (b) Splitting into a moving and a static part connected by update layer.

The basic idea of the SSMUM is to split the computational domain into a moving and a static part, respectively. Subsequently, a thin layer of elements – the update layer – is added, which connects the moving and static mesh portions. For illustration, we will consider two objects in relative translational movement, e.g., a box which moves along a static wall (see Figure 2a). For this example, a splitting of the computational domain into a moving portion, a static portion and the update layer is shown in Figure 2b. The moving mesh will perform a rigid body displacement as soon as the object, and thus its boundary, starts to move. Due to the movement of the interface between the moving mesh and the update layer, the elements in this layer undergo a shear deformation. When the movement proceeds, the elements will become more and more distorted. To counter this, the SSMUM applies a connectivity update in the update layer, i.e., the elements will then be comprised of a different, yet neighbouring set of nodes. This step is based on update node information: Each node of an affected element knows by which node it has to be replaced in the update procedure. A projection of the solution field is not necessary, since the nodes keep their position.

In order to address the periodicity, the moving domain is assumed to be built-up of characteristic blocks. Furthermore, all blocks have identical discretization, i.e., the same mesh. The modeling of the movement by means of the computational grid is achieved through the following idea: The translational, unidirectional movement in physical space is mapped to a movement along a virtual ring in a more abstract space. To set up this ring, the mesh for the moving domain is closed between its physical boundaries Γ_{in} and Γ_{out} by an additional copy of the characteristic mesh block (see Figure 3a). The boundary of this block will be denoted as Γ_{virt}. We let Γ_{in} and Γ_{virt} coincide in the abstract space and, thus, the moving mesh now represents a closed ring. As one can conclude from the figure, the geometric periodicity is automatically implied, since we have assumed that all blocks are identical. However, this does not enforce periodicity with respect to the solution field, since the mesh block, which enters the domain, is not the same one, which leaves the domain. For the solution process, the mesh portion in the virtual region between outlet and inlet is deactivated. It is only used to model the mesh deformation.



(a) **(b)**

Figure 3. Virtual ring in abstract space for the example of two moving squares. (a) Moving mesh closed by additional mesh block (dashed). (b) Closed moving mesh combined with static mesh by update layer.

We connect the moving and static mesh portions by adding a thin layer of hand made elements, which aggregate the individual sub-meshes into one (see Figure 3b). In contrast to the original version of the SSMUM, the update criterion is not (directly) based on the shape of the elements in the update layer. Instead, an update is triggered if any mesh point, which is part of the interface between the moving mesh portion and the update layer, enters the virtual region and disappears in the physical space.

2 Numerical Results

2.1 Validation: 2D Couette Flow

For the validation of the VR-SSMUM, we used the classical 2D Couette flow test case. At steady state, the analytic solution for the velocity field $\mathbf{u} = (u, v)^T$ is given as $\mathbf{u}^* = (\bar{u}y/H, 0)$, where $\bar{u}$ is the velocity of the upper plate. Since the movement requires an unsteady simulation, we prescribed $\mathbf{u}^*$ as initial condition and checked that the velocity field is not significantly distorted by the mesh update method. In Table 1, the maximum relative error δ^u_{rel} is given for the first time steps. Although we can see some influence of the method when a connectivity update is performed and previously deactivated elements enter the computational domain, the error remains sufficiently small.

Step	1 - 5	6	7	8
$\delta_{\text{rel}}^{\mathbf{u}} \cdot \mathbf{10^{14}}$	0.0173	5.98	0.260	0.0520

Table 1. 2D Couette flow: maximum relative error for x-velocity δ_{rel}^{u}. In time step 6, a connectivity update was performed and previously deactivated elements entered the computational domain.

2.2 Use Case: 2D Packaging Machine

The VR-SSMUM has been applied for the simulation of the flow and temperature field of a single fluid component inside a packaging machine. The setup is as follows: A conveyor belt carries a number of packages through the stationary machine casing. At the top of the casing several nozzles are located. Underneath, remaining fluid is expelled through a box. The packages move from left to right through the machine and pass the nozzles which inject hot fluid. Figure 4 shows results for the flow field, i.e., the pressure distribution and the x-velocity, respectively.

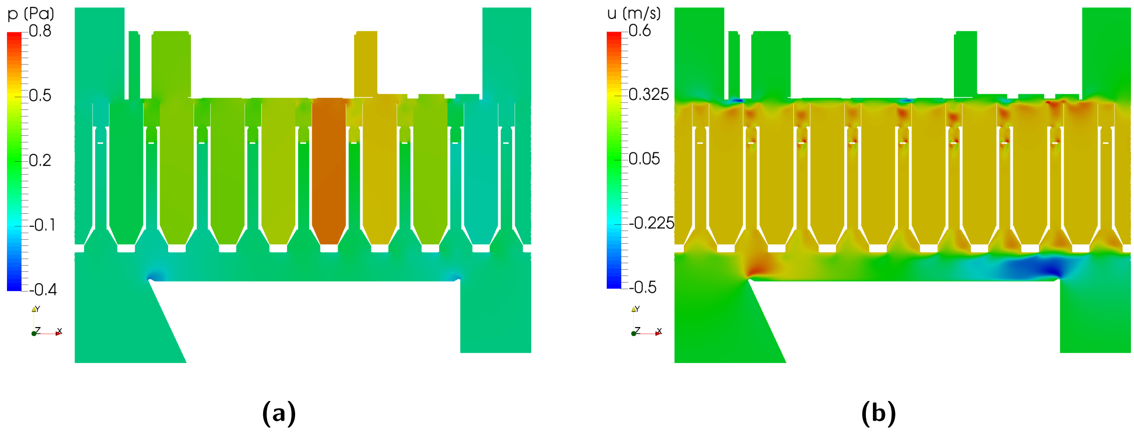


Figure 4. 2D packaging machine: results for (a) pressure and (b) x-velocity field.

Conclusions

We presented the VR-SSMUM as an interface tracking approach to efficiently and accurately handle deforming-domain problems including relative translational motion. The method has been validated by means of the 2D Couette flow test case. Furthermore, we applied the approach in the context of simulating packaging machines and showed results for the flow field inside.

References

[1] M. Behr and T. Tezduyar. The Shear-Slip Mesh Update Method. *Computer Methods in Applied Mechanics and Engineering*, Vol. 174(3):p. 261–274, 1999.

[2] S. Elgeti and H. Sauerland. Deforming Fluid Domains Within the Finite Element Method: Five Mesh-Based Tracking Methods in Comparison. *Archives of Computational Methods in Engineering*, Vol. 23(2):p. 323–361, 2016.

[3] T. Tezduyar, M. Behr, and J. Liou. A new strategy for finite element computations involving moving boundaries and interfaces–the DSD/ST procedure: I. The concept and the preliminary numerical tests. *Computer Methods in Applied Mechanics and Engineering*, Vol. 94(3):p. 339–351, 1992.