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Approaches to the computational modelling of soft tissues related to cutting

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1 Introduction

Physically accurate but versatile and fast simulation of soft tissue behavior during cutting is required for technological advances of robotic systems interacting with tissue due to the lack of real life testing possibilities [1]. As alternative to mesh-based methods as FEM, flexible bodies can also be implemented using particle approaches from computer graphics [2]. This paper proposes a particle-based implementation for simulating soft tissue deformation and cutting.

2 Implementation

The implementation is based on a regular hexahedral grid of particles which can collide with each other and the ground using a soft-collision method. To this, we add connections $\mathbf{c}$ between neighbouring n particles j in the initialisation step of the simulation using a spring-damper model. The force equation with particle position $\mathbf{x}$, velocity $\mathbf{v}$, spring coefficient k, damping coefficient d and initial displacement $\Delta\mathbf{x}_{ij,0}$ is given as

$$\mathbf{f}_{connection}(i) := \sum_{j=1}^{n} k((\mathbf{x}_i - \mathbf{x}_j) - \Delta\mathbf{x}_{ij,0}) + d(\mathbf{v}_i - \mathbf{v}_j)\,.$$

The connections can be removed during the simulation as soon as a certain force limit is reached. Cutting can now be simulated using either just a contact force or a defined cutting force. The calculation is performed with *nVidia Warp* [3] on a GPU, where each particles force can be evaluated parallelised for each simulation step. A symplectic euler integration shown in figure 1 is used to update each particles velocity and position based on the updated force.

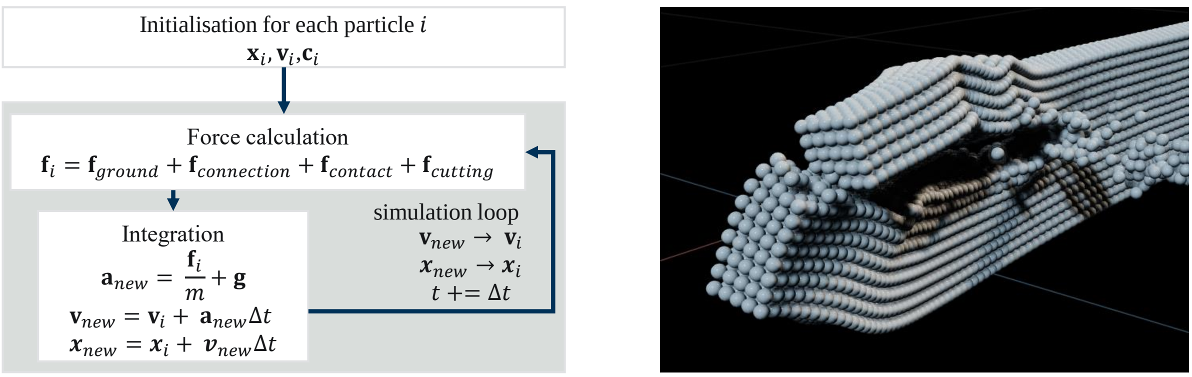

Figure 1: Left: Simulation algorithm for each particle. Right: Visualisation of soft body particles while cutting.

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3 Benchmark - Flexible Beam

To evaluate the physical accuracy of the connected particles representing a flexible body, we compare the step-response of a beam simulated as a flexible multibody in *Matlab Simulink Simscape* [4] with our custom implementation, as shown in figure 2. One challenge however, is the definition of spring-coefficient between the particles. For the benchmark, this was manually tuned.

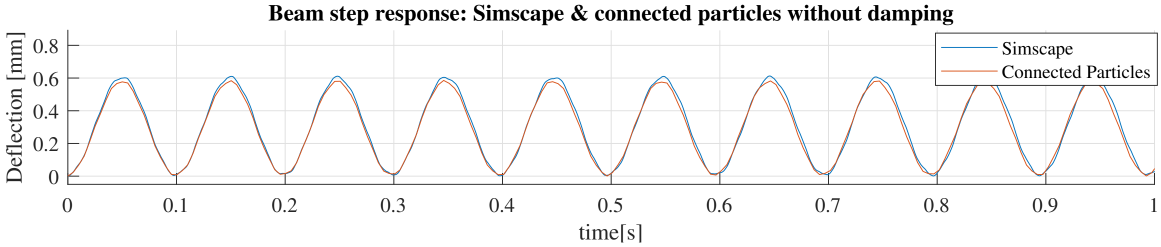

Figure 2: Free step-response of a flexible beam simulated in *Simscape* and with our method.

In contrast to the *Simscape* model, the stability of the particle simulation does increase for low material stiffness and vice versa. This makes the framework suitable for soft bodies.

4 Conclusions

The presented implementation provides both, a physically accurate behavior for a flexible body and the possibility to perform cutting at arbitrary positions at runtime without any recalculation or reformulation of the initial data structure. This and the parallelised evaluation makes the algorithm comparably fast, especially for materials with low stiffness.

However, there are aspects which are not considered in the implementation. First, the spring-damper parameters are manually tuned depending on the size and number of particles in the simulation and not directly derived by any material value or model. Second, material behavior as volume perseverance or anisotropic material is not implemented. Finally, the accurate simulation of cutting physics is still unsolved.

Acknowledgement

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References

[1] Philip Long, Wisama Khalil, and Philippe Martinet. Robotic Deformable Object Cutting: From Simulation to Experimental Validation. *In European Workshop on Deformable Object Manipulation*, 1(1), 2014.

[2] Matthias Müller, Bruno Heidelberger, Marcus Hennix, and John Ratcliff. Position based dynamics. *Journal of Visual Communication and Image Representation*, 18(2), 2007.

[3] Miles Macklin. Warp: A high-performance python framework for gpu simulation and graphics. `https://github.com/nvidia/warp`, 2022. NVIDIA GTC.

[4] Y. Van Weddingen S. Miller, T. Soares and J. Wendlandt. Modeling flexible bodies with simscape multibody software. `https://de.mathworks.com/content/dam/mathworks/tag-team/Objects/s/Modeling-Flexible-Bodies-Simscape-Multibody-171122.pdf`, 2017.