# Predicting model deformations for predictive force feedback in haptic bilateral teleoperation applications: Towards complex interactions in haptic bilateral teleoperation

Stefan Stoicescu

[1]EEMCS, Delft University of Technology, The Netherlands

TU Delft

## Introduction

- **Teleoperation** is a multidisciplinary field that focuses on enabling human operators to control remote manipulation devices in real-time. This capability could be crucial for scenarios such as space and deep-sea exploration, urban search and rescue missions, or even nuclear plant maintenance.
- **Real-time feedback** (visual, haptic) from the remote environment has the capacity to greatly increase the usability of teleoperation systems systems, however is highly subject to network issues, such as delay and packet loss.
- **Model Mediated Teleopertation** (MMT) proposes the use of local model to provide operators with near-instantaneous haptic feedback, regardless of any connection issues.
- While models for general haptic interactions exist for systems with good environment knowledge or limited dimensionality, models tailored for 3D spaces filled with deformable objects (such as granular soils), have proven to be more challenging, due to the innate difficulty of balancing accuracy, and runtime speed.

## Research Question

**"How can we predict model deformation for cutting interactions in haptic bilateral teleoperation applications?"**

To explore this research question, we need to examine several subquestions:

- "How can deformable materials be represented within a physics simulation?"
- "How can cutting an object be simulated within a physics engine?"
- "How can the physics engine keep track of changes in an object's shape?"
- "Which metrics can be used to approximate feedback for cutting?"

## Methodology

In order to create a simulation capable of handling complex cutting interactions with deformable objects, we drew inspiration from previous work regarding real-time soil simulations:

- Li and Moshell [1] discuss a 2D model for soil slippage and manipulation. At its core, the approach divides the surface of the terrain into discrete "columns" of sand, and then shifts material from one column to another, based on material properties and Newtonian physics.
- Benes, Dorjgotov, Arns, *et al.* [2] present a haptic and visual simulation of sand, in order to facilitate interactive 3D modelling. The model described in the paper simulates sand displacement and erosion using heightfields.
- Geiger [3] presents a voxel-based method for simulating interactions with granular media. The approach outlined in the paper enables 3D manipulation of soil, by tracking the velocity of individual sand voxels.

## Terrain Cutting Simulation

Our terrain simulation builds upon the techniques used in the aforementioned papers, by utilising heightfields to keep track of material deformation. The model builds upon a C++ Bullet Physics MMT simulator provided by TU Delft's Networked Systems group. Our additions can be neatly divided into two categories

- **Terrain System**: A custom terrain instatiator capable of constructing shapes from heightmap textures by creating an array of column-shaped kinematic rigid-body objects.
- **Cutting System**: A simulated blade that calculates collisions with heightmap objects via ray-box intersections. Affected rigid-body objects undergo a downwards translation to match the height of the blade.

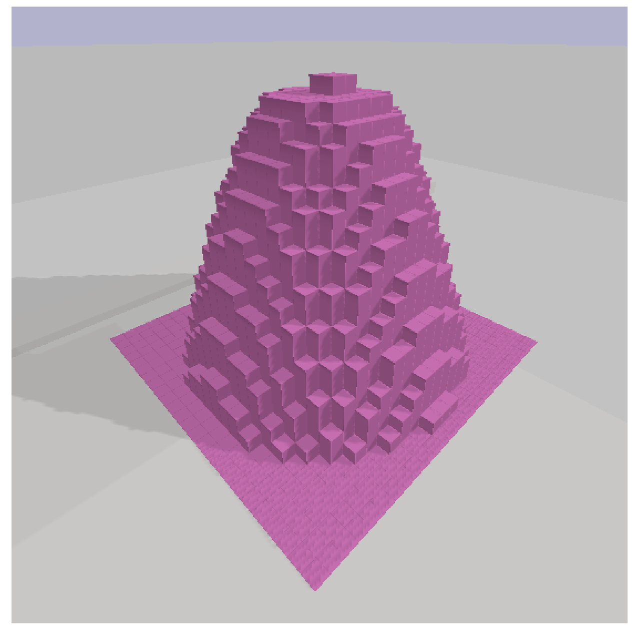

Figure 1. An in-engine screenshot of a shape created by the terrain system. The pink mound-like structure is made up of numerous column-shaped objects.

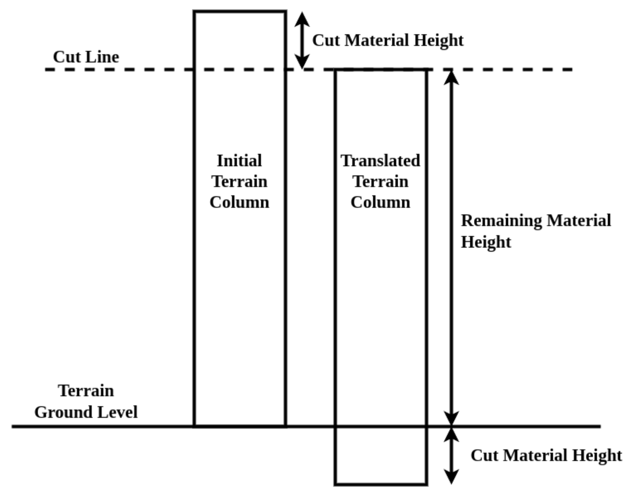


Figure 2. A diagram showing a single terrain column before and after being cut. The column undergoes a downward translation in order to simulate the removal of the material above the blade.

## Experimental setup

In order to gauge the accuracy and usefulness of our proposed model, two experiments were drawn up. During the testing process we considered the length of blade's contact with the terrain to be a good proxy for force feedback calculations.

1. The first experiment aims to measure the impact of heightmap resolution on the resulting cutting feedback. The system was tested by scaling a base heightmap texture to 5 different resolutions. A single horizontal slice was then performed for each texture size.
2. The second experiment aims to show that he proposed heightmap-based model can efficiently keep track of changes in an object's shape throughout a series of successive cuts.
   The system was tested by measuring blade contact length for three different sequences comprised of three distinct cuts (refered to as A, B and C).

## Results

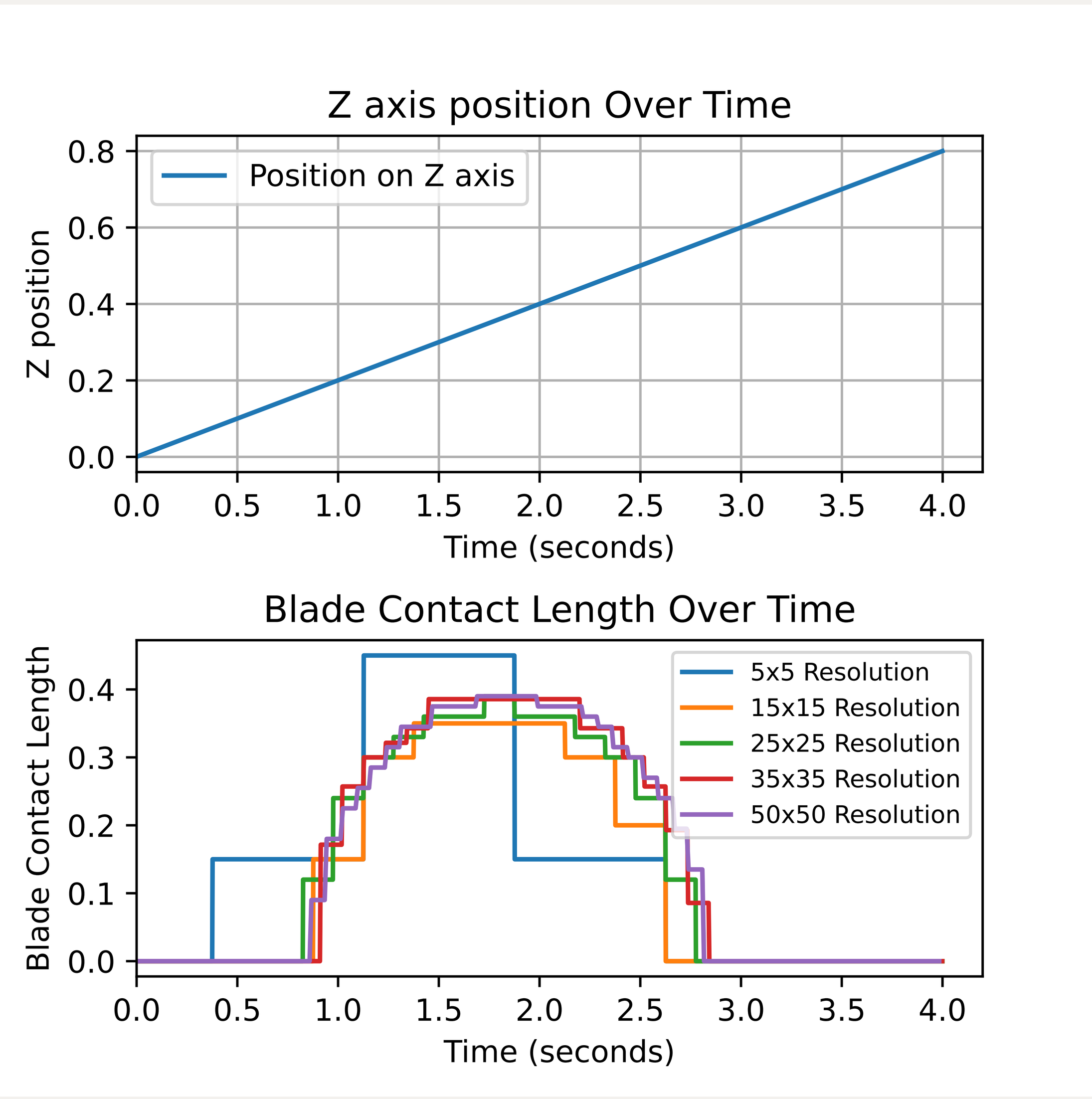


Figure 3. Results for experiment 1.

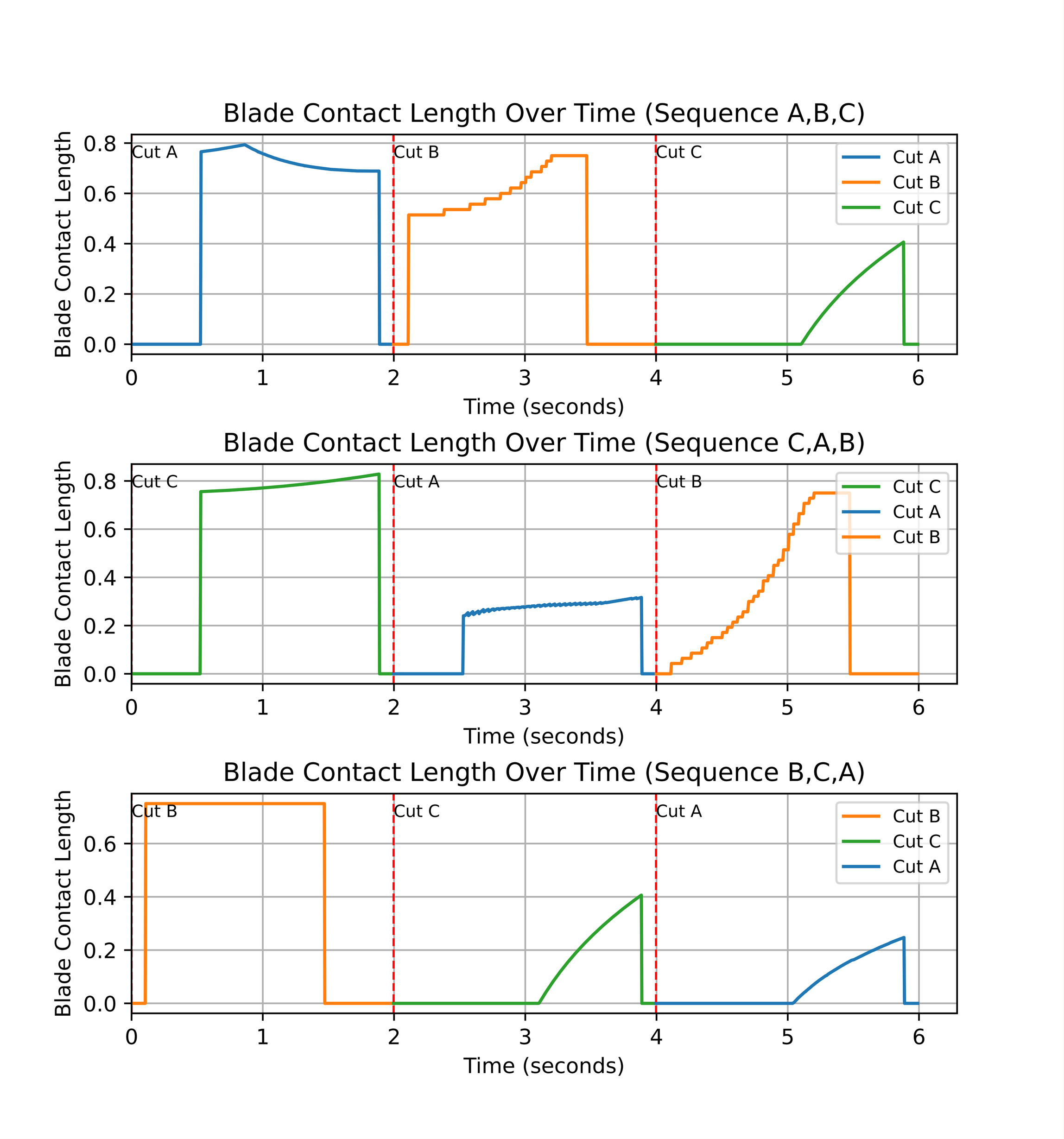


Figure 4. Results for experiment 2.

## Conclusion

- While resolution can have a significant impact on the performance of the model, contact path measurements begin to display consistent behaviour at relatively low texture sizes.
- Higher heightmap resolutions result in reduced judder in contact length readings.
- The model is able to keep track of material deformation for complex, successive cuts, suggesting that heightmaps are well suited for intricate teleoperation tasks.

## Limitations

- While the model provides consistent behaviour, heightmaps simplify the three-dimensional complexities for an object. In the model all terrain above the blade vanishes.
- High-resolution heightmaps (above 50x50) were not tested, due to performance limitations stemming from the implementation of the terrain system.
- The simulation does not provide haptic feedback to a haptic controller, only cutting metrics.
- The effects of network delays could not be tested.

## Future Work

- **Enhanced Soil Modelling**: Expand the model to support soil erosion and flow, from one column to another.
- **Broader Range of Interactions**: Expand the model to support a wider range of complex interactions, such as scooping.
- **Haptic Model**: Expand the model to provide force feedback to haptic controllers such as the "Novint Falcon".
- **Network Simulation**: In conjunction with a haptic model, the effects of network delays and packet loss could be explored via a user study.

## References

[1] X. Li and J. M. Moshell, "Modeling soil: Realtime dynamic models for soil slippage and manipulation," *Proceedings of the 20th annual conference on Computer graphics and interactive techniques*, 1993. [Online]. Available: `https://api.semanticscholar.org/CorpusID:207176936`.

[2] B. Benes, E. Dorjgotov, L. Arns, and G. Bertoline, "Granular material interactive manipulation: Touching sand with haptic feedback,", Jan. 2006.

[3] A. D. Geiger, "A voxel-based approach to the real-time simulation of sands and soils," AAI28141638, M.S. thesis, 2015, ISBN: 9798662598959.

Supervisors: Ranga Rao Venkatesha Prasad, Kees Kroep

CSE3000 Research Project

stoicescu@student.tudelft.nl