Multibody simulation of contacts between arbitrary meshes of CAD quality: recent results, open problems and possible developments

Alessandro Tasora, Dario Mangoni, Dario Fusai

Dept.of Engineering and Architecture
University of Parma
Via delle Scienze, 181/A, Parma, Italy
[alessandro.tasora, dario.mangoni, dario.fusai]@unipr.it

EXTENDED ABSTRACT

1 Abstract

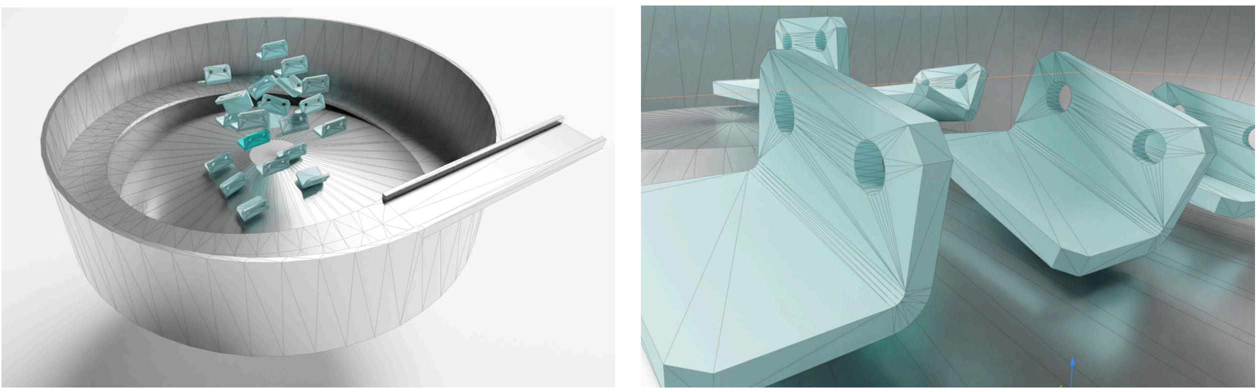
One of the open problems in the field of multibody dynamics is the stable and robust simulation of contacts between rigid or flexible parts when their shapes are defined by means of meshes of arbitrary complexity, as those exported by modern 3D CADs. Efficient collision detection algorithms have been developed in the last three decades, but in most cases they introduce simplifying assumptions, such as the convexity of the shape or the absence of interpenetration. If one aims at the simulation of arbitrary triangle meshes, there are only few classes of algorithms that can offer robustness and efficiency: in this work we discuss the most promising solutions among these, and we propose an algorithm that draws on a conventional triangle proximity test, enhanced by a Minkowski sum that greatly improves robustness.

2 Problem description

Many algorithms for the simulation of contacts are based on a simplified approximation of the real shape of objects: to this end, the shape is approximated by means of convex primitives such as spheres, ellipsoids, boxes, cylinders, convex polytopes, etc., or clusters of these primitives. Algorithms such as MPR or GJK offer very high performance and robustness, and in fact this method is often used in videogames, virtual reality etc. However, this approximation often requires a preprocessing stage with manual adjustments. On the other hand, it would be nice to bypass the burden of this approximation and use directly the triangle mesh as exported from a CAD modeler, however at the time of writing, the robust and stable collision detection between triangle meshes is still a challenging topic.

From our experience in the field of multibody simulation, the ideal method should provide the following properties: it must be able to work with arbitrary meshes with the only requirement of meshes being watertight; it must be fast, scaling to cases involving thousands or millions of triangles; it must be easy to embed in pre-existing time integration schemes; it must be robust, hence avoiding situations where triangles get tangled and jam when they should not; it should support the case of deformable shapes without major overheads; possibly it should be able to tolerate a certain amount of interpenetration.

In this field, a recent breakthrough has been presented in [1] , introducing the incremental potential contact (IPC) method that, for the first time, guarantees global injectivity (lack of interpenetration) with arbitrary 3D meshes. This generated a new class of algorithms with the attractive property of guaranteed robustness, although at the cost of computing continuous collision detection and by requiring a tight coupling between the collision algorithm and the time stepping algorithm. At the other side of the spectrum, another noteworthy advancement is the method recently discussed in [2], where signed distance fields (SDF) are used to simulate a large amount of complex shapes in contact. An attractive property of this second class of methods is that they



(a) (b)

Figure 1: Example: multibody simulation of a bowl feeder: (1a) triangle mesh exported from a CAD, (1b) closeup showing difficulties such as concavity, thin walls and tiny details

can fit well into pre-existing time stepping schemes, however they require 3D arrays of scalar data that, even when leveraging modern GPU hardware and smart optimizations, either use a large amount of memory in sake of precision, or use less memory at the cost of missing small-scale details. A third class of methods is the more conventional approach of computing distances or intersections between triangle pairs, then use some heuristics to improve robustness by discarding or correcting contact pairs that would generate tangled situations in case of interpenetration. The difficulty resides in the fact that there is no global consensus on efficient and reliable heuristics. We propose a development based on this third class of algorithms that improves robustness by using fat triangles, and we implemented it in a non-smooth dynamic solver that can be used for robotics and other applications that deal with CAD models [3].

3 Proposed method

The robustness of methods based on the distance between triangle pairs is severely impacted by cases where meshes are intersecting. One can bypass the issue of tangled meshes by replacing triangle meshes with Minkowski sums of triangle meshes and spheres of radius r_s, that is, each triangle is considered as a thick triangle with rounded edges. This amounts to computing the distance between triangle pairs and creating the two contact points at an offset r_s: if the solver guarantees that the interpenetration is always less than $2r_s$ (because of tolerances, numerical round off, or compliant contact models), then the inner meshes are guaranteed to never intersect and to provide a well posed computation of triangle distances.

From our tests, large r_s provides better robustness, whereas small r_s approximates better the original mesh, but limits the performance of the timestepper in the sense that small time steps would be needed in order to bound the numerical error within a small range.

A drawback of this approach, though, is the fact that the original CAD mesh is simulated as it is coated by a layer of thickness r_s, with rounded edges. If this side effect is not acceptable, we can perform a pre-processing stage where the CAD mesh is shrunk by an inner offset r_s: in this way the outcome is like collision happens between the original CAD mesh but without the coating effect. The only remaining approximation is a rounding on the edges. We remark, anyway, that computing the shrinking of 3D meshes is not always trivial, because in the most general case the offset algorithm should support self intersections and rebuilding of mesh topology (for example, small details of size less than $2r_s$ would disappear, and in general the simulation of zero-thickness parts such as clothes or paper would not be possible).

Further enhancements are represented by a filtering stage that removes candidate contact pairs that are not residing in the normal cone to the Minkowski sum, and by extending the offset also by an additional outward amount that captures potential contacts before fat triangles are intersecting.

4 Conclusion

We report two new advancements in the field of collision detection that can be relevant in the field of multibody simulation of complex shapes as those exported by CAD tools. We also present an extension of the triangle-triangle collision approach that can offer sufficient robustness in many engineering cases that we tested, provided that one can accept a rounding of the edges with some prescribed radius.

References

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