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Modeling contact interactions between triangulated rounded bodies for the discrete element method

Bart Smeets[a,b,*], Tim Odenthal[a,b], Janos Keresztes[a], Simon Vanmaercke[a], Paul Van Liedekerke[a,c], Engelbert Tijskens[d], Wouter Saeys[a], Hans Van Oosterwyck[b], Herman Ramon[a]

[a] *KU Leuven – MeBioS, Kasteelpark Arenberg 30, 3001 Heverlee, Belgium*
[b] *KU Leuven – Biomechanics Section, Celestijnenlaan 300c, 3001 Heverlee, Belgium*
[c] *INRIA – Domaine de Rocquencourt, France*
[d] *University of Antwerp – Department of Mathematics and Computer Science, 2020 Antwerp, Belgium*

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Highlights

- We describe a method to calculate contact forces between arbitrary rounded bodies.
- Bodies are represented as triangulated surfaces with associated radii of curvature.
- Contact forces are calculated by integrating Hertz contact pressure.
- For spheres, convergence towards the Hertz solution upon mesh refinement is shown.
- Gravitational packing of spheres, pears and gummy bears is shown as an example.

Abstract

Calculating contact forces between complex shapes for performing Discrete Element Method (DEM) simulations is a long standing problem with no unique ideal solution. In this work, a new method to calculate interactions between arbitrary rounded bodies is presented. Each body is represented by a triangulated surface mesh, in which each triangle is associated with a unique radius of curvature. Then, normal contact forces are calculated by numerically integrating a (Hertz) contact pressure formulation over the contact area between two contacting particles. This results in a mechanistic contact description that is converging with refinement of a given triangulation and directly uses physical material properties as parameters of the contact model. After showing convergence upon mesh refinement towards the Hertzian solution, the error for non-spherical curvatures is investigated and the new model is compared with an indentation experiment of a pear-shaped object. Finally, the method is demonstrated in a simulation of gravitational packing by simulating packing of spheres, pear-shaped as well as gummy bear-shaped objects.

Keywords: Discrete element method; Arbitrary shapes; Triangulated mesh; Contact model

* Corresponding author at: KU Leuven – MeBioS, Kasteelpark Arenberg 30, 3001 Heverlee, Belgium. Tel.: +32 494845165.
E-mail address: bart.smeets@biw.kuleuven.be (B. Smeets).

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1. Introduction

A correct model of particle shape in the Discrete Element Method (DEM), is not only a model that approximates the volume taken up by the particle, but also the normal direction at each point on the particle's surface. The latter is crucial for calculating correct contact forces as it determines the direction of both normal and tangential contact forces. Classical contact theories such as the Hertz model [1] impose a third requirement: the radius of curvature at the point of contact. From the perspective of DEM, the most straightforward particle shape is a perfect sphere.[1] The normal direction at a given contact point is trivial to calculate and the radius of curvature is directly given by the sphere's radius.

Representing arbitrary particle shapes in DEM while accounting for these three requirements remains a challenge. Various other shape models have been used, such as ellipsoids [2–4], poly-ellipsoids [5], superquadric surfaces [6,7], polyhedra [8,9] and convex bodies [10]. These more complex shape descriptions allow for DEM simulations of a wide range of non-spherical particles. However, calculating contact properties and contact forces in general requires extensive computational effort. Furthermore, formulations for obtaining proper contact forces cannot always be directly related to mechanistic contact theories, nor to the intrinsic mechanical properties of the particle, such as the Young's modulus. In the case of two contacting polyhedra, the overlapping volume can be assumed to be proportional to the stored elastic energy, but deriving an appropriate contact force from this energy requires classification between various types of contact [8].

Another approach for representing arbitrary shapes is by making use of composite geometries: multiple shape primitives are connected in a rigid or non-rigid fashion to approximate more complex geometries [11]. By connecting spheres of various sizes, the volume as well as the surface normal direction of arbitrary smoothed shapes can be accurately represented, if the spheres are chosen carefully [12,13]. The local curvature, however, cannot be correctly accounted for as constraints on the sphere size can be imposed by the volume representation. Also, the approximation is made that the local curvature is spherical, where in reality the principal radii of curvature are not necessarily equal and can even be negative. Because of this, locally linearized contact force models are often used. Furthermore, adjustments have to be made to account for the occurrence of multiple simultaneous contacts between two particles, which otherwise may lead to non-physical collision behavior [14,15].

In this work, a new way of representing arbitrary particle shapes in DEM is presented. By accounting for the volume, as well as the normal direction and the local average curvature, it tries to improve on the method of sphere composites. The new shape model is introduced based on the Hertz model for the contact between elastic spheres. In principle, Hertz-like models can describe contact between smooth surfaces – even with cusps – almost exactly in an asymptotic sense. Surfaces with asperities will fail only if the Hertz model itself breaks down.

Section 2 details how contact forces between triangulated rounded bodies can be calculated for DEM simulations. In Section 3, the model is first validated by showing convergence upon mesh refinement towards the Hertz solution for spherical bodies. Next, the error made in contact force calculation for non-spherical curvatures is estimated and the model is compared to an indentation experiment of a pear-shaped object. Finally, an example DEM simulation is given where gravitational packing is compared for spheres, meshed spheres, pear-shaped and gummy bear-shaped objects.

2. Model description

The purpose of this work is to demonstrate a new method for modeling arbitrary shapes in DEM. The solution is derived from classical contact theory and based on the following ideas:

1. The arbitrary shape is represented as a triangulated surface. Each triangle in this surface has a well-defined local curvature (see Section 2.1). Therefore, each triangle can be associated with a unique spherical surface that has the local radius of curvature as radius and intersects with all three triangle points.
2. For each contact candidate an effective overlap distance is calculated. If the effective overlap distance is positive, a non-zero contact force can be expected (see Section 2.3).
3. Contact forces are determined by explicitly integrating the pressure from classical Hertz contact theory over the contact area between two rounded shapes (see Section 2.4).

[1] Or a disk in two dimensions.