

Accurate contact detection and response in fibre assemblies with friction.

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1. Introduction

Simulating dry interacting fibres is relevant to a diverse set of applications, ranging from the fundamental understanding of fibre entanglement [1] to the realistic animation of hair in special effects [4, 6] and the virtual prototyping and design of a wide set of new rod-based materials in the fields of engineering [5]. Since the 2000's, a number of numerical models for fibres subject to frictional contact has therefore been developed both in Computer Graphics and Mechanical Engineering, with variability across the validity range, computational performance, and predictability. While the former community has focused on the simulation of extremely complex scenes (thousands to millions long interacting fibres under large displacements), often at the expense of little quantitative validation, the latter has generally favoured much simpler scenarios (small deflection of beams, low number of fibres and contact points, regularised friction laws) albeit with extensive care for predictability.

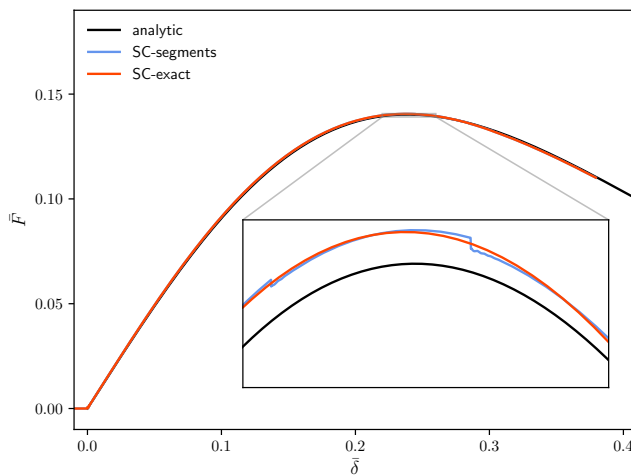


Figure 1: (Left) Comparison of the normalised force \bar{F} as a function of the normalised displacement $\bar{\delta}$ in the frictionless three-point-bending test using a 2D implementation of the *Super-Helix* model to simulate the rod. Two detections schemes are compared, segments discretisation and exact distance computation, to the analytic solution. (Right) Application of our full pipeline to the challenging simulation of a comb passing into a wisp of hair: 2025 tightly contacting super-helices are simulated with dry friction, resulting in 33100 contacts on average, which are accurately detected using our new curve-curve detection algorithm [3] and resolved precisely with our non-smooth Coulomb friction contact solver so-bogus [4].

The goal of this work is to explore novel algorithms to enhance the predictability of fibre assembly simulators, without sacrificing the complexity of the target scenarios. Our present study is precisely aimed at evaluating and improving the accuracy of the *forces* computed among fibre assemblies. Computing frictional contact forces emerging from fibre systems in an accurate manner is indeed fundamental to the proper understanding of micro-mechanisms at the origin of macro-behaviours such as adhesion or crackling in fibre assemblies, which still remain poorly understood nowadays [1, 8]. On an applicative point of view, predicting forces correctly would further allow to enhance considerably the predictability of material design, especially for systems requiring high-fidelity restitution of some target properties like the strength, feasibility and sustainability of the design [7], but also the user sensorial experience related to touch or audio sense of reality [10].

2. Contribution

Our work relies on the super-helix [2] curvature-based discrete model for Kirchhoff elastic rods, coupled with contact and friction through the non-smooth so-bogus solver [4]. This coupled simulator has been carefully validated *geometrically* in 2D and 3D configuration, against the dimensionless cantilever and pinning tests [9].

When analysing the contact forces yielded by this numerical model on the classical three-point-bending test, for which an analytical law can be derived, we note the occurrence of spurious jumps which, to the best of our knowledge, were never reported before. We demonstrate that these artifacts are actually directly linked to the *low-order contact detection* being used between the fibre and the obstacles. Low-order detection, based on segment proxys, is classically used due to its simplicity of treatment, even for fibre models possessing a higher-order geometry like super-helices. We show that spurious artifacts occur whatever the fibre model and contact response solver used, as soon as a segment-segment detection scheme is employed.

To remove such numerical artifacts in the force profile, which can accumulate to yield large force errors, we introduce an efficient high-order detection algorithm [3]. Our method aims at finding the closest point between a pair of curves, with respective centreline parametric equations $a(s)$ and $b(s)$, by looking for the two curvilinear abscissa s_1 and s_2 that minimise the distance fonction $D(s_1, s_2) \equiv \frac{1}{2} \|a(s_1) - b(s_2)\|^2$.

In the 2D case, we show that there exists an analytic solution to our problem. In the general 3D case, the problem becomes non-convex and challenging to solve: we devise a branch-and-bound approach to find pairs of closest points in an accurate and efficient way. Our algorithm proves to be particularly well-suited to super-helices, but can be adapted to other family of curves, provided there is a bound on their second derivative. We combine that narrow phase detection to a broad phase that prunes obvious cases and add a final pass that merges close contact at the junction between discretised elements.

We demonstrate the validity of our detection algorithm on the 2D three-point bending test (see Figure 1, left), and the scalability and robustness of our method on a challenging 3D scenario involving tens thousands of frictional contacts (Figure 1, right).

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