3D Inverse Dynamic Modeling of Strands

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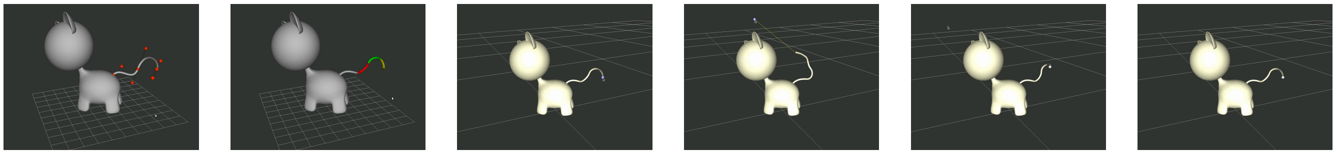

Figure 1: *A consistent dynamic strand synthesis pipeline. From left to right: The artist models a cat tail by editing a 3D spline, which is automatically converted into a dynamic rod model (super-helix) at rest under gravity. The tail can then be physically animated while retrieving its initial shape at the end of slight (possibly strong) motions.*

1 Motivation

1D deformable structures, often called *strands*, are ubiquitous in the real world. They range from plants (grass, lianas, stalks) to creatures organs (hair, tail, tentacles) and manufactured objects (cables, ropes). The realistic modeling and animation of such objects is essential for representing convincing virtual environments. Most often, the design pipeline is split in two distinct parts: the geometry creation process itself, namely *geometric design*, followed by the computation of motion, namely *animation*. For the sake of flexibility and control, the geometric design generally relies on a pure geometric process that allows the user to interactively edit curve primitives such as splines. In contrast, the animation of strands is often considered as a passive and complex phenomenon that can be realistically captured using physics-based simulation.

In this poster we address the lack of consistency between these two steps. Indeed, no trivial solution is currently available to convert 3D geometric curves into physics-based primitives while keeping the precise shape chosen by the user as a stable resting configuration. Many approaches have been developed for deforming slender geometries while ensuring a nonlinear behavior, allowing for plausible keyframed animation. However, pure geometric methods cannot capture typical inertial effects (e.g., buckling), and such complex transitional states have to be manually defined by the user. Conversely, modeling strands in a physics-based environment based on indirect operations such as cutting or frizzing may be tedious and not intuitive enough for an artist who, having a precise shape in mind, would definitely prefer the flexibility of geometric methods.

2 Contributions

We propose a new solution for bridging the gap between the geometric modeling of 3D strand-like objects and the physics-based animation of material rods. Our approach allows the artist to freely design strands using standard tools (spline curves). The geometric curve is then automatically converted into a physical model (super-helix [Bertails et al. 2006]) that faithfully matches the chosen shape at rest under gravity. The core of our approach relies on a 3D extension of the 2D technique presented in [Derouet-Jourdan et al. 2010], leading to the *inverse statics* of the 3D super-helix model.

Geometric fitting We propose a new and robust algorithm for fitting a 3D spline to a piecewise helix, with some direct control over the number N of helical elements and thus over the time performance of subsequent animation. As a helix is characterized by constant curvature and torsion, we approximate the curvature-torsion profile of a spline by a piecewise constant function. Each constant is computed as the mean curvature-torsion of an element of the spline evenly cut into N pieces. Knowing the position and tangent at clamped end, we are able to reconstruct a piecewise helix that will serve as an initial approximation of the spline. Starting from this initial guess, we apply the Levenberg-Marquardt least-squares optimization algorithm in order to refine the approximation and get a piecewise helix that closely matches the input spline.

Static fitting We automatically identify the physical parameters of the super-helix model such that the piecewise helix resulting from previous step exactly matches the rest shape of the rod model under gravity. This is achieved by a natural 3D extension of the 2D technique proposed in [Derouet-Jourdan et al. 2010]. The main difference is that analytical computations become much more tricky in 3D. In practice, we use Mathematica®to precompute the analytical formulae. The natural curvatures and torsion of the super-helix can then be retrieved by simply solving $3N$ linear equations. Similarly as in the 2D case, we get a sufficient condition for stability: $\frac{\text{stiffness}}{\text{mass}} > S$, where S only depends on the geometry of the rod.

3 Results and Discussion

We are able for the first time to automatically and consistently generate 3D dynamic strands from an input geometry. Unlike previous approaches, our method guarantees that strands closely match the input curves when simulated at rest under gravity, and go back to this user-defined rest shape after slight – possibly strong – motion.

Our geometric fitting proves fairly robust as strict convergence occurred for 95% of the curves (smooth to wavy) we have tested, in a reasonable amount of time (a few seconds to a few minutes on a standard PC for fitting 4 to 12 helical elements). In the 5% remaining cases, the fitting actually converges to some local minimum which is nevertheless visually close to the original curve.
In the future we would like to take into account contact forces in the statics fitting process. This would allow the user to create strands in contact with a surface (such as hair colliding with the body) without having to artificially increase the stiffness for preserving stability.

References

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