White Paper

fleXengine -
Highly accurate real-time simulation system of hoses, cables and wiring harnesses

A highly accurate physically correct numerical simulation of flexible cables and hoses with circular cross-section has been achieved for real-time interaction applications. Non-uniform material composition is supported including multi core, shielded or isolated cables; braided or multi layered hoses. Collision detection and contact simulation are enabled, reproducing complex nonlinear behaviour of cables/hoses in contact with arbitrary shaped rigid geometry. Arbitrary connections of cables among each other and with rigid geometry are supported. As a result, wiring harnesses with multiple branches can be modelled and tested in real time, allowing for digital mock-ups and enhanced product design.

Technology Background

The interactive simulation of the physical behaviour of compliant parts has been requested by industry for many years. Cables, wires and hoses play an essential role in the assembly of any industry product. To consider physical cable properties in the digital design phase of a product helps detecting design problems, such as those caused by collisions with rigid parts and other compliants. It also helps to determine production requirements, such as cable length and the respectively allowed tolerance. This analysis significantly reduces the costs for real mock-ups.

The behaviour of a flexible object is described by the theory of elasticity in terms of several material constants, i.e.

1. Young's module (Y) and Poisson's ratio (v); or
2. Lame coefficients (λ,μ); or
3. Bending and torsional stiffness (B,C), etc.

The material properties are related by equivalence formulae:

$\lambda=Y*v/(1-2*v)/(1+v)$
$\mu=Y/(1+v)/2$
$B=Y*\pi*(d_1^4-d_2^4)/64$
$C=\mu*\pi*(d_1^4-d_2^4)/32$

In the case of composite structures, e.g. multilayered cables/hoses corresponding effective constants can be either measured directly in experiments or computed using an additive formulae, e.g.

$B=\Sigma_i Y_i \pi (d_{1i}^4-d_{2i}^4)/64$

where the sum is taken by layers. Additionally required quantities are the length (L), external and internal diameters of the cable/hose/layer (d_1, d_2), volumetric mass density (ρ), as well as positions (t) and orientations (R) of the ends of the cable/hose, which can be conveniently organized into 4x4 matrices of the form

$$M = \begin{array}{|c|c|} \hline R & 0 \\ \hline t & 1 \\ \hline \end{array}$$

These matrices serve as conductors of user interaction to a flexible object.

The theory of elasticity provides equations describing static and dynamical behaviour of the flexible object under user interaction. Also various approximate models are known valid in special restricted situations.

The main challenge for the numerical simulation of the long cables and hoses consists in the fact that the elastic equations become *ill-conditioned* in the limit L>>d. This effect is related with the appearance of so called rigid body modes. Their physical meaning is that bending of a long cable has small energetic cost because the segments of the cable move mostly like a chain of rigid bodies. On the other hand, stretching of the cable has got high energetic costs. This leads to a high condition number for the corresponding system matrix and slow convergence of numerical methods. The problem persists for both, for the exact elastic equations and for their approximate analogs. As a result, the standard approaches give usually off-line or in the best case at almost interactive performance of simulations. This purely numerical problem is additionally complicated by physical instabilities and singularities inherent to cables and hoses, i.e. buckling, contact bifurcations, etc.

The robustness of the implemented scheme has been shown for a variety of realistic situations in interactive design environments. To guarantee the accuracy, the cables, wiring harnesses and hoses have been evaluated intensively together with several automotive companies. The results of the experimental validations show that shapes of wiring harnesses and hoses computed by fleXengine coincide at high accuracy with experimentally measured shapes. fleXengine solves exact non-linear elastic equations at machine precision, therefore the deviation between fleXengine results and experiment was always on the level of 1% (since the experiments have been carried out with a 1% error).

fleXengine is the only solution for simulation of cables and hoses combining physical precision and update rate more than 80 fps on a P4 2GHz PC.