SIMULATION OF CONTACT FORCES BETWEEN CYLINDRICAL SLACK FLEXIBLE TETHERS IN SELF-COLLISIONS

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Tethered systems are used in a variety of different applications, perhaps the most notable of which is in underwater exploration. In the operation of underwater Remotely Operated Vehicles (ROVs), the only viable means of control is through its tether which also provides power, communications and telemetry. Due to the high cost of ROV systems as well as the risks involved in their operation, computer simulations are required for the training of their pilots.

Tethers have a large effect on the ROV's dynamics [1, 2], it is therefore imperative that, in computer simulations, the forces acting on a tether are taken into account. This includes the forces involved in the contact of the tether with the environment or with itself (*i.e.*, self-collision).

This work describes a compliant contact model for tether self-contact situations. In the simulation of tether contact, one must rst determine if self-collisions are occurring. A method of detecting self-collisions was proposed in [3] where a simplistic force model was used to demonstrate the effectiveness of the collision detection method. This work extends this work by developing an contact model based on the calculation of the intersection volume between contacting objects. This model is similar to those found in [4, 5, 6].

The volume of interference between two skew cylinders can be found analytically. There are four independent variables which in uence the volume of intersection (Figure 1): the radii of both cylinders (r_1 and r_2), the angle α between their centre lines which provides their relative orientation, as well as their separation distance. The volume is calculated using these four variables by integration. Although most numerical integrators method would do the job, due to required computational ef ciency for real time simulations, a 5-point Gaussian quadrature is recommended as there is minimal loss of accuracy for the large performance gain over other numerical integration methods.

When two objects come into contact, a pressure region is formed between them. This pressure is caused by the elastic properties of the two bodies undergoing deformation during contact. Integrating this pressure over the area can provide the total force keeping them apart can be calculated as:

$$\text{Pressure-based force:} \quad F = \int \sigma \, da \tag{1}$$

$$\text{Stress:} \quad \sigma = E\epsilon \tag{2}$$

$$\text{Deformation:} \quad \epsilon = \frac{dr}{r} \tag{3}$$

$$\text{Volume:} \quad dV = dr \, da \tag{4}$$

$$\text{Volume-based force:} \quad F = \int \frac{E \, dV}{r} \tag{5}$$

As seen in equations (1) to (5), the volume can represent the deformation of both cylinders, therefore to nd the force from deformation of one cylinder, half of the interference volume is used in equation (5).

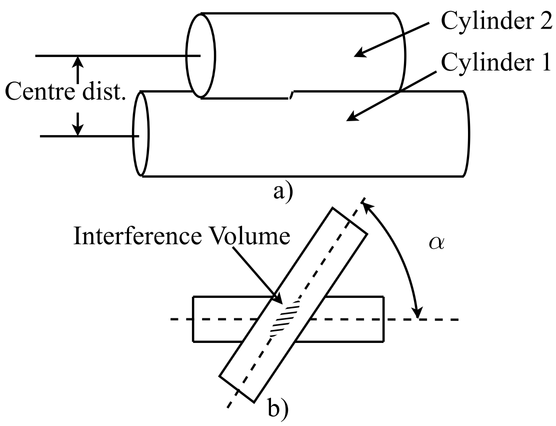

Figure 1: Two intersecting cylinders where a) shows the minimum separation distance and b) shows α as the angle between them

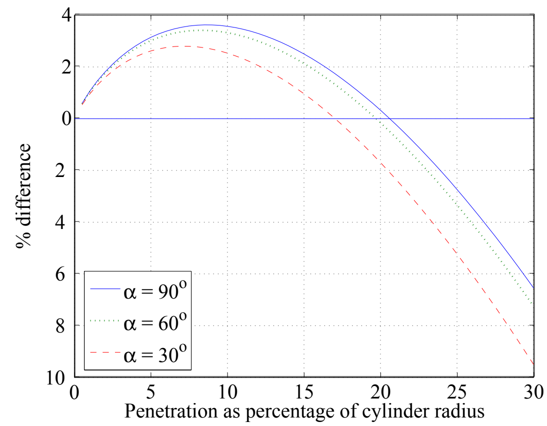

Figure 2: Percentage difference between contact patch are of the Hertzian model and the volume of interference model.

In order to verify the accuracy of this force, it was compared with Hertzian model of general contact due its wide acceptance by the scienti c community. The force provided through the volume of interference model is plugged into the Hertzian model which can provide the major and minor axes of the contact patch. Through a comparison of the contact patch area from the volumetric model and the Hertzian model the accuracy of the volumetric model is determined.

Figure 2 shows the percentage differences between the contact patch areas of both the volumetric method described here and the Hertzian contact. The interference geometry model described here adheres to the Hertzian contact model at almost any angle to within $\pm$ 5% as long as penetration depth is maintained under 25% of the tether's radius.

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