UW Ligament Model

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Citation of Ligament Model

The spring force in this ligament model was adapted from J. Wismans (1980). An additional source for information on this ligament model is Blankevoort, et al. (1991).

1. Wismans, J., *A Three-dimensional Mathematical Model of the Human Knee Joint*. 1981: Druk Wibro Helmond.
2. Blankevoort, L. and R. Huiskes, *Ligament-bone interaction in a three-dimensional model of the knee.* Journal of biomechanical engineering, 1991. **113**(3): p. 263-269.

SimTK Related Project

https://simtk.org/home/uwsimulation

Introduction

This ligament model was developed by J. Wismans [1] to represent a ligament as a non-linear spring element consisting of a non-linear "toe" region and a linear region (Fig. 1). We have modified this ligament model to additionally include a normalized damping force.

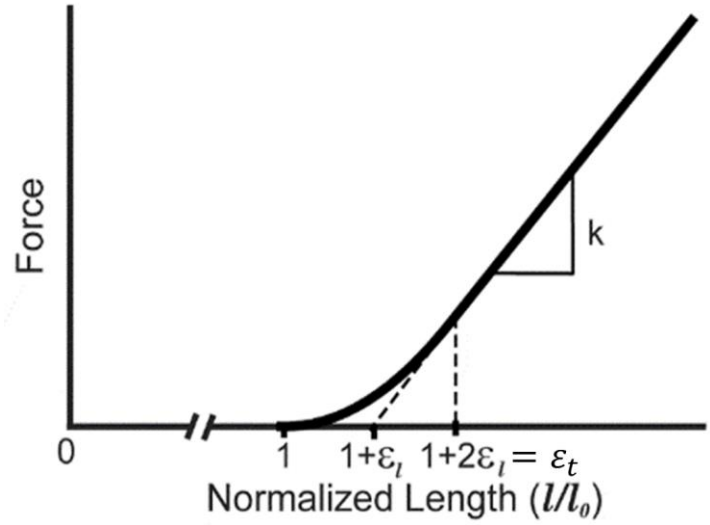

Figure 1 – Normalized spring force length curve

Governing equations

Spring Force

$$F_{spring} = \begin{cases} \frac{1}{2\varepsilon_t} k\varepsilon^2, & 0 \le \varepsilon \le \varepsilon_t \\ k\left(\varepsilon - {\varepsilon_t}/{2}\right), & \varepsilon > \varepsilon_t \\ 0, & \varepsilon < 0 \end{cases} \quad (1)$$

Damping Force

$$F_{damping} = kc\dot{\varepsilon} \quad (2)$$

Total Force

$$F_{total} = F_{spring} + F_{damping} \quad (3)$$

The spring force (Eq 1) is a piece-wise function made of quadratic and linear portions and is dependent on the strain in the ligament. The quadratic and linear relationships can both be modified by two terms, the ligament linear stiffness (*k*) and the ligament transition strain (ε_t). The ligament transition strain is defined as the strain at which the force-strain relationship transitions from linear to quadratic. This notation of the force-strain relationship is a slight modification from that presented in Wismans [1] and Blankevoort et al. [2], in that we include the ligament transition strain (ε_t) rather than the horizontal intercept of the linear portion of the function (ε_l). However, both are numerically equivalent.

The damping force (Eq 2) is a normalized damping force and is dependent on the strain rate of the ligament. This relationship can be modified by changing the ligament linear stiffness (k) and the normalized damping coefficient (c). The total force (Eq 3) is the combination of the spring force and the damping force.

Variables

The following are the properties of the ligament model that need to be defined within your model file (.osim file).

linear_stiffness (*k*)
The linear stiffness of the ligament with units of Newtons/strain (N).

ligament_transition_strain (ε_t)
The strain at which the ligament force-strain relationship transitions from quadratic to linear.

reference_strain
The ligament strain in the reference position. The reference position is defined at full-extension.

reference_length
The ligament length in the reference position with units of meters (m). The reference position is defined at full-extension.

normalized_damping_coefficient (*c*)
Damping coefficient from (Eq 2) in units of Seconds (s). For guidance, c=0.003 for all ligaments in the UW Knee Model.

Use of Plugin

How to Load Plugin

1. If you have not loaded any plugins for OpenSim before, create a plugin folder within your OpenSim directory (i.e. C:\OpenSim 3.3\plugins).
2. Copy and paste the dynamic link library (UWLigamentPlugin.dll) into the plugins folder.
3. Run OpenSim.
   Note: This plugin is currently only available for the 64 bit version of OpenSim. If the 32 bit is needed, please send an email to mvignos@wisc.edu.
4. At the top of the GUI, select Tools > User Plugins > UWLigamentPlugin.dll
5. Check the box that says “Always load this library on entry” and select OK. Now this plugin will load whenever you run OpenSim.

How to include ligament within model

Below is a screen shot of a ligament definition within a model file (Fig. 2). For reference on how to define this ligament within your model, select Help > XML Browser at the top of the OpenSim GUI. Select UWLigament for the Class Name. This will allow you to copy and paste the basic ligament definition into your model and modify the parameters to meet your own needs.

```
<UWLigament name="MCLd1">
    <!--Flag indicating whether the force is disabled or not. Disabled means that the force is not active in subsequent dynar
    <isDisabled>false</isDisabled>
    <!--the set of points defining the path of the ligament-->
    <GeometryPath>
        <!--The set of points defining the path-->
        <PathPointSet>
            <objects>
                <PathPoint name="MCLd1-P1">
                    <location> -0.0017455 -0.00045737 -0.037269</location>
                    <body>femur_distal_r</body>
                </PathPoint>
                <PathPoint name="MCLd1-P2">
                    <location> -0.00021515 -0.031853 -0.031379</location>
                    <body>tibia_proximal_r</body>
                </PathPoint>
            </objects>
        </PathPointSet>
        <!--The wrap objects that are associated with this path-->
        <PathWrapSet>
            <objects>
                <PathWrap>
                    <wrap_object>Med_Lig_r</wrap_object>
                    <method>hybrid</method>
                </PathWrap>
            </objects>
        </PathWrapSet>
        <!--Used to display the path in the 3D window-->
        <VisibleObject name="display">
            <!--Set of geometry files and associated attributes, allow .vtp, .stl, .obj-->
            <GeometrySet>
                <objects />
                <groups />
            </GeometrySet>
            <!--Three scale factors for display purposes: scaleX scaleY scaleZ-->
            <scale_factors> 1 1 1</scale_factors>
            <!--transform relative to owner specified as 3 rotations (rad) followed by 3 translations rX rY rZ tx ty tz-->
            <transform> -0 0 -0 0 0 0</transform>
            <!--Whether to show a coordinate frame-->
            <show_axes>false</show_axes>
            <!--Display Pref. 0:Hide 1:Wire 3:Flat 4:Shaded Can be overridden for individual geometries-->
            <display_preference>4</display_preference>
        </VisibleObject>
        <!--Used to initialize the colour cache variable-->
        <default_color>0.9 0.9 0.9</default_color>
    </GeometryPath>
    <!--slope of the linear portion of the force-strain curve of ligament-->
    <linear_stiffness>500</linear_stiffness>
    <!--strain at which ligament force-strain curve transitions from quadratic to linear. Commonly 0.06 in literature.-->
    <ligament_transition_strain>0.06</ligament_transition_strain>
    <!--strain of ligament when joint is at full extension-->
    <reference_strain>0.04</reference_strain>
    <!--length of ligament when joint is at full extension-->
    <reference_length>0.032</reference_length>
</UWLigament>
```

Figure 2: Screen capture showing ligament definition within a model file.