2010.01.03

**Tracking surfaces (villi) in 3D**

The purpose of this tutorial is to provide a brief introduction to the methods implemented for the 3D scanning of arbitrary surfaces. New fields have been added to the tracking screen, but mainly, the tracking can be done automatically.

The major modification is that the plane of the orbit can now be placed in three orthogonal planes, xy (such as before), xz and yz. The planes are selected in the move page in the tracking screen. This is used to initialize tracking. In few words, first an image must be done in any one of the 3 planes and then tracking must be initiated. Once started, the plane of the orbit can be changed using decision logic. To understand how the decision is made we must first explain basic features of the scanning system. A new plot has been added so that the user can follow the direction of the movement and detect the plane of the orbit while tracking.

The scanner used for tracking is oriented in a fix direction in the lab physical space. The coordinates of the villi center of mass are expressed in the lab reference frame, denoted by $x_{0\_s}, y_{0\_s}, z_{0\_s}$, where “s” stays for scanner. In the figures the x axis is red, y is blue and z is black. The local direction of the villus is in green color.

If the average orientation of the villus is along the z, defined by the angle $\phi$ with respect to the lab axis the most convenient orientation for the orbit is in the xy plane. The angle $\phi$ is the angle of the green segment with respect to the z (black axis).

When the $\phi$ angle becomes larger than 45 degrees then there are other planes of orientation of the orbit which can be more efficient for tracking the villus axis.

If the angle $\theta$ with respect to the x (red) axis is smaller than 45 degrees, then the most convenient plane for tracking is yz plane.
If the $\theta$ angle is larger than 45 degrees, the most convenient plane for the orbit is in the $xz$ plane.

The automatic switch of the plane of the orbit follows the decision logic:

```plaintext
phi := arctan2(sqrt(sqr(dxlab)+sqr(dylab)), abs(dzlab))*rd; // calculation of the angle with respect to z
theta := arctan2(abs(dylab), abs(dxlab))*rd; // calculation of the angle in the xy plane
if (phi < phi_threshold) and (abs(dzlab) > delta) then // the angle phi is ok, the plane of the orbit is xy
  begin
    use_plane(0);
    phi_threshold := 50; // increase the threshold to have some hysteresis
  end
else
  begin
    phi_threshold := 40; // the angle phi is too large, decide which other plane to use
    if (theta < 40) and (abs(dxlab) > delta) then // use the yz plane
      use_plane(2);
    if (theta > 50) and (abs(dylab) > delta) then // use the xz plane
      use_plane(1);
  end
```
To avoid frequent switching of plane of orbit, an interval of 10 degrees is used in the selection algorithm. The auto switch plane flag must be checked for this algorithm to be active.

The auto-tracking starts after about 100 orbits. It is based on the differential movement in the 3 orthogonal directions. The increments along each axis are smoothed with a moving average of about 90 orbits. Then the average angles with respect to the z direction and with respect to the x axis in the xy plane are calculated. Depending on the values of these angles, a decision is made about the best plane for the orbit. Note that only 3 planes are allowed, rather than a continuous of planes. If the algorithm will perform poorly, I will change this part to allow either a continuous of planes or at least many more planes, such as every 30 degrees for each of the 2 angles $\theta$ and $\phi$. This is not a major deal, but for the moment I will like to test how the simple 3-plane algorithm performs. Essentially the same decision logic could be used but with more preset values for the two angles. The timing of the waveform switching is about 1-2 ms so that tracking should not be disturbed by having more complex waveforms.

I have tested the algorithm only on simulated data. There are several parameters to adjust. The size of the hysteresis loop before switching planes must be optimized depending on the sample and S/N ratio. Also the size of the minimum movement along the 3 axes must be optimized.