# MRI Reconstructed Surface Smoothing Without Shrinkage

Jayavel Arumugam
Department of Mechanical Engineering
Michigan State University, East Lansing, MI 48823, USA
*e-mail*: ajyavel@gmail.com

## 1 Problem

MRI reconstructed surfaces of the heart have geometrical artifacts. Such artifacts could lead to instabilities in organ level numerical simulations. Such surfaces need to be regularized in order to obtain good and stable model simulations. Smoothing is a standard way to regularize the surface details. However, the smoothed surfaces lead to shrinkage and in turn changes in volume. This makes model validation with measured pressure-volume (PV) data difficult. Here, the surfaces are smoothed using Taubin's filter [1].

Given an appropriately defined surface $x^0$, smoothing operation of the surface is defined as

$$x^{'} = f(K)x^0 \tag{1}$$

where $K$ is the surface 'Laplacian'. The matrix function $f(.)$ is typically a polynomial. In one variable, it corresponds to a transfer function. The smoothing operation is repeatedly performed over $n$ iterations resulting in $x^n = f(K)^n x^0$.

## 2 Solution

The standard Laplacian smoothing uses the following choice of $f(.)$ in equation 1:

$$f(k) = (1 - \lambda k) \tag{2}$$

Laplacian smoothing in equation 2 with $0 < \lambda < 1$ removes high frequency components from the surface. This also leads to shrinkage and reduction in volume. The surface shrinks to a point in the limit $n \to \inf$.

Based on ideas from signal processing, Taubin [1] proposed modifications to $f(K)$ of the form

$$f(k) = (1 - \lambda k)(1 - \mu k) \tag{3}$$

where $k \in [0, 2]$, $0 < \lambda < 1$, $-1 < \mu < 0$ (check?), and $\mu < -\lambda$. Negative value of $\mu$ in equation 3 deshrinks the surface at each smoothing step. This smoothens the surface and also maintains the shrinkage to be lesser compared to the standard Laplacian smoothing.

# 3 Code

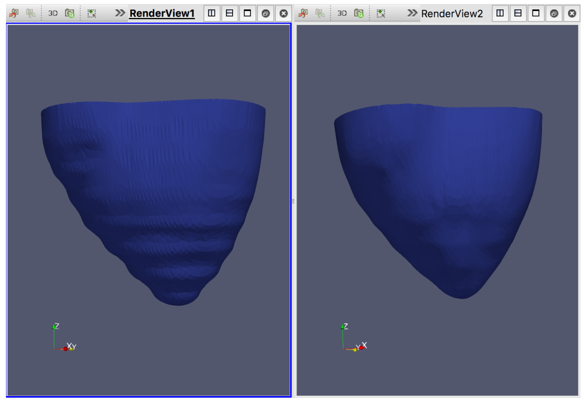


Figure 1: Initial surface (left). Smoothened surface using Taubin's filter (right).

The class **vtkSmoothPolyDataFilter()** in VTK library implements the standard Laplacian filter. The class **vtkWindowedSincPolyDataFilter()** in VTK library implements the Taubin's filter.

Listing 1: Laplacian filter using VTK library

```
smoother = vtk.vtkSmoothPolyDataFilter()
smoother.SetInputConnection(vReader.GetOutputPort())
smoother.SetNumberOfIterations(1000)
```

Listing 2: Taubin's filter using VTK library

```
smoother = vtk.vtkWindowedSincPolyDataFilter()
smoother.SetInputConnection(vReader.GetOutputPort())
smoother.SetNumberOfIterations(50)
```

# 4 Results

An initial surface of a reconstructed epicardium and the corresponding smoothened surface (Taubin) are shown in figure 1. Two views each of the Taubin's (50 iterations) and the Laplacian filter (1000 iterations) are shown in figure 2. Taubin's filter results in comparatively less shrinkage. The amount of volume change for the two filters based on different values of iteration $n$ are reported in table 1.

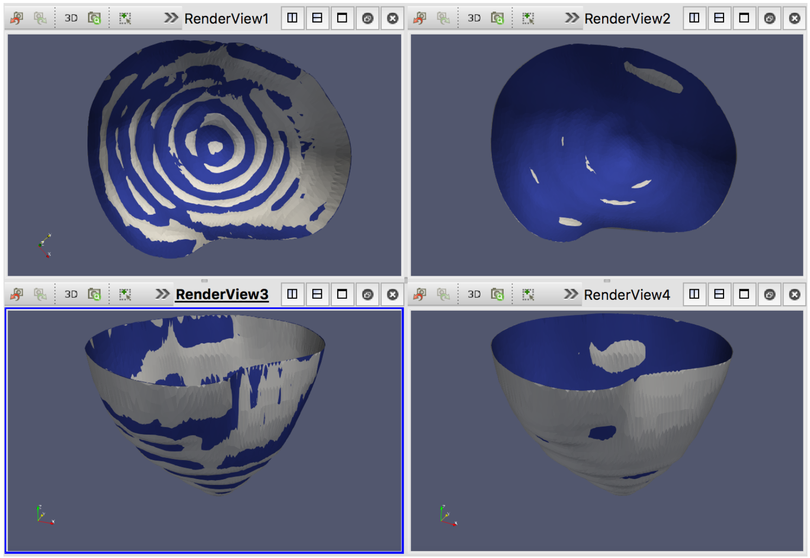


Figure 2: The original surfaces are in grey. The smoothed surfaces are in blue. Results of the Taubin's filter are in the left. The Laplacian filter (right) results in comparatively more shrinkage.

## 5 Conclusion

Smoothing of MRI reconstructed surfaces using Taubin's filter [1] results in less shrinkage compared to the Laplacian filter. The reliability of such smoothed surfaces towards mesh generation, myofiber generation, and stable numerical simulation of PV loops need to be further studied.

Table 1: Comparison of volume changes

| Iteration (n) | Lapalcian filter | Taubin's filter |
|---|---|---|
| 5 | 93.50 | 93.24 |
| 10 | 93.48 | 94.39 |
| 50 | 93.37 | 94.09 |
| 100 | 93.22 | 95.21 |
| 500 | 92.04 | 91.93 |
| 1000 | 90.60 | 91.04 |
| 5000 | 79.86 | 90.89 |

## References


[1] G. Taubin, "A signal processing approach to fair surface design," in *Proceedings of the 22nd annual conference on Computer graphics and interactive techniques*, pp. 351–358, ACM, 1995.