3D Volume Registration with Gaussian Process

AM207 - Monte Carlo Methods, Stochastic Optimization, Spring 2015

Group Members:

Danyang Chen − danyangcheng@g.harvard.edu

Ruitao Du – ruitaodu@g.harvard.edu

Yingzhuo Zhang – yingzhuozhang@g.harvard.edu

Introduction

Subject motion during an MRI scan can cause substantial corruption in images. To detect movement, we acquire a series of 3D volumes every 2.5-3 seconds from the navigator with crude resolution. The first volume of the series is treated as "ground truth", and the goal is to estimate movement by rotating the rest of the volumes in the series to match the "ground truth".

The problem with traditional interpolation methods (Figure1) such as linear interpolation is the variation of interpolation uncertainty across the volume, whereas volume rotation using Gaussian process is proposed to reduce such uncertainty. (Wachinger 2014) Therefore, the main goal for the project is to develop accurate interpolation kernels for Gaussian process to detect movement between the series of volumes.

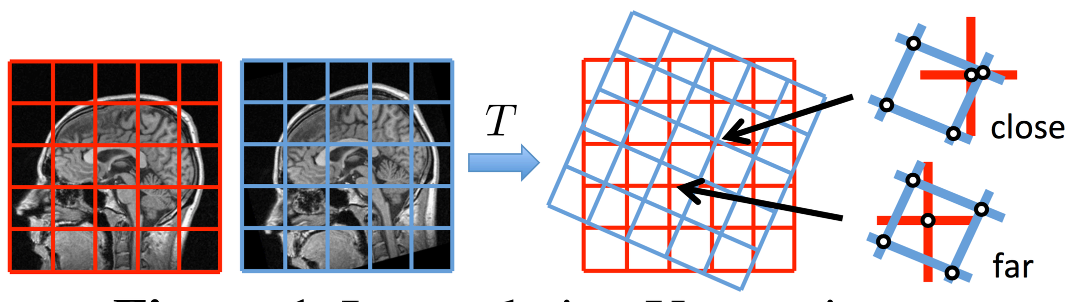

Figure 1. Interpolation Uncertainty.

Approach

1. Rotation with Gaussian Process

A Gaussian process can be written as $\mathcal{GP}(m(x), k(x, x'))$, where $m(x)$ and $k(x, x')$ are infinite dimension mean vector and covariance matrix. In this case, the mean and covariance matrix specify a distribution over each voxel of a volume.

We work with the squared exponential kernel:

$$k(x,x') = exp\left[-\theta\left||x-x'|\right|^2\right]$$

Given rotated volume J, the target J* follows the posterior distribution:

$$p(J^*|J; X^*, X) = \mathcal{N}(\mu_J, \Sigma_J)$$

with mean and covariance:

$$\mu_J = k(X^*,X)\left[k(X,X) + \sigma_J^2 I\right]^{-1} J$$

$$\Sigma_J = k(X^*,X^*) - k(X^*,X)\left[k(X,X) + \sigma_J^2 I\right]^{-1} k(X,X^*)$$

The values of θ for the resolutions are chosen as:

Resolution	10mm	8mm	6.4mm
θ	29.83	45.62	80.28

2. Motion Detection

For rotation from -6 to -4.1 degrees, we computed the sum of squared differences between the "ground truth" volume and the rotated volume using Gaussian process. The degree with the minimum SSD is presented as the motion detection result.

Traditional interpolation methods such as linear and cubic interpolation introduce uncertainty across volumes when doing volume registration. Gaussian Process (GP) is proposed to reduce such uncertainty using its covariance matrix and thus reduces interpolation error. This project demonstrates that volume registration with GP on 3D MRI scans can increase interpolation accuracy compared to linear interpolation.

Data

The data are MRI scans of pineapples. We have 3 series of pineapple volumes with known rigid movement at 3 different resolutions (6.4mm, 8mm, 10mm). The first volume is the initial position of the object, and object is then rotated 5 degrees around one axis.

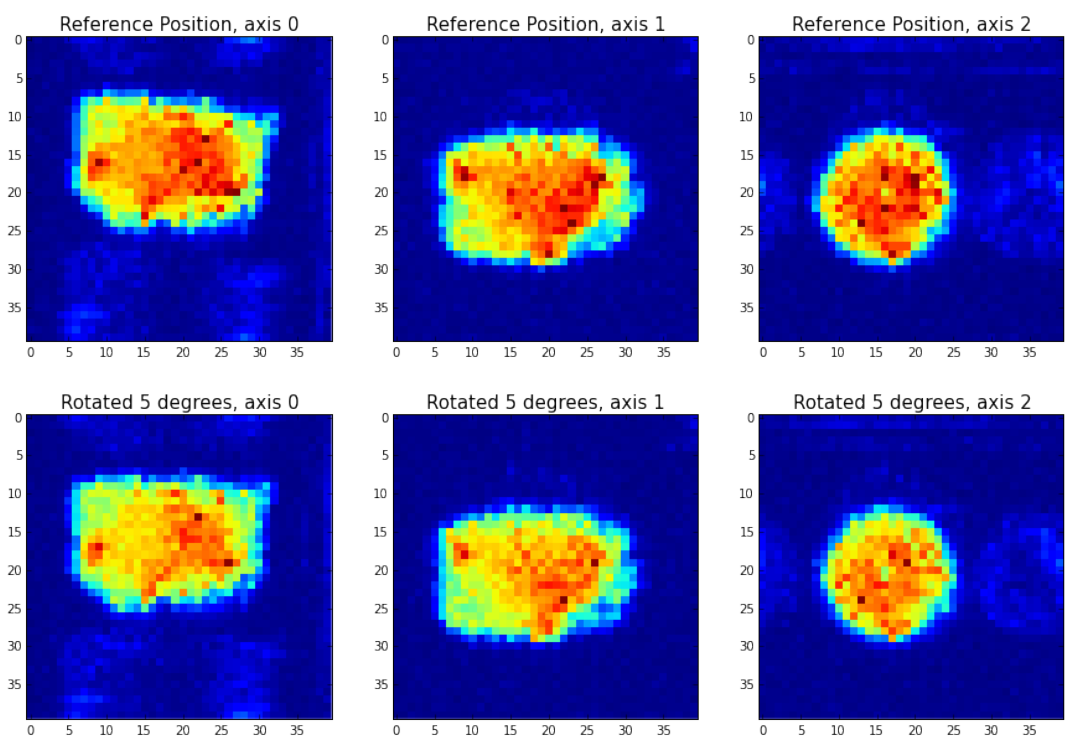

Figure 2. Sample Data with 6.4mm Resolution.

Results

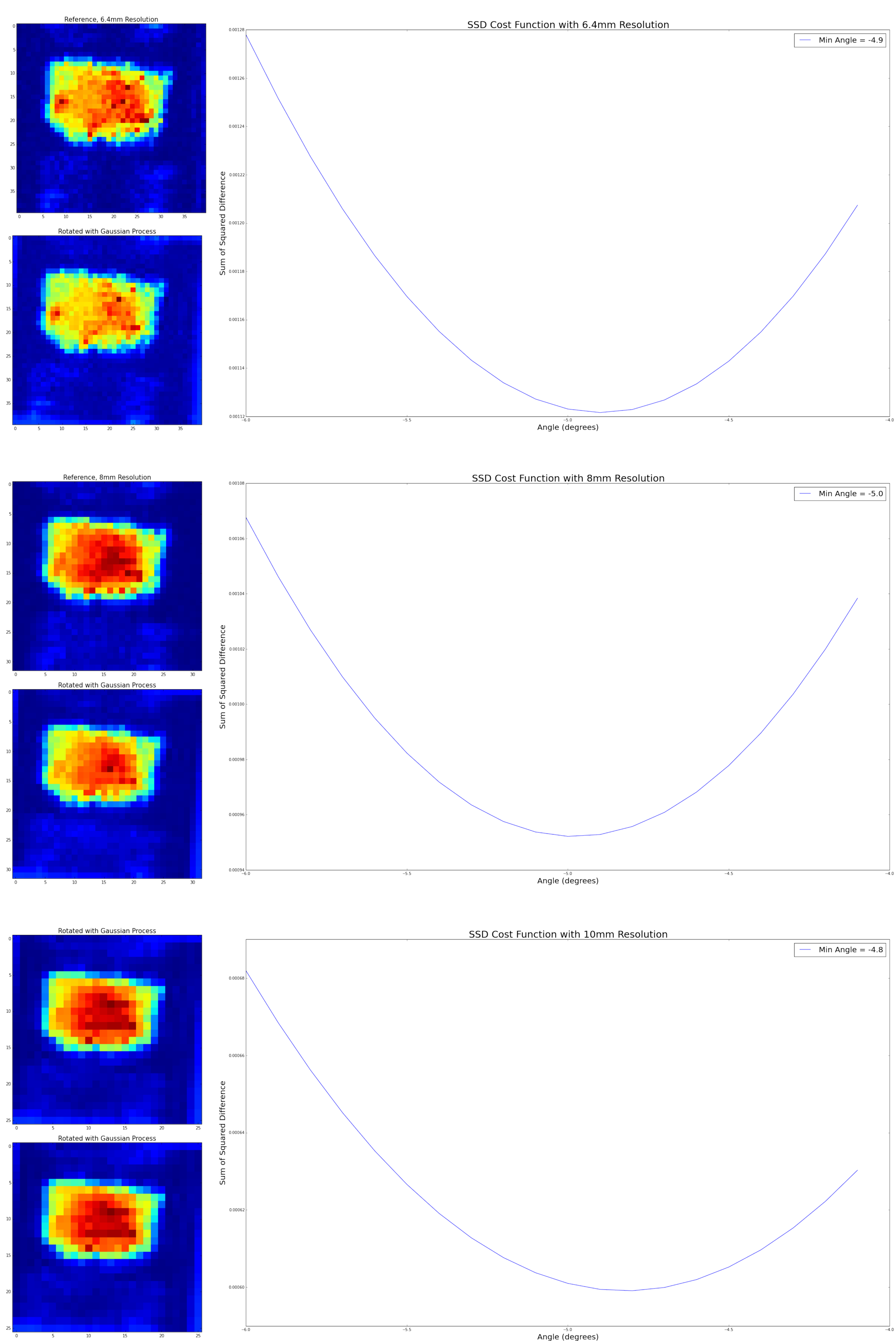

Figure 3. SSD comparison between different resolutions

The true movement between the volumes is a 5-degree rotation along axis 0. According to sum of squared differences, motion detection with Gaussian process is exactly 5 degrees with 8mm resolution; however, Gaussian process did not achieve 5 degrees with the other resolutions. The results are 4.9 and 4.8 degrees with 6.4mm and 10mm resolution respectively.

The plot below shows the SSD results on the same data set from trilinear interpolation.

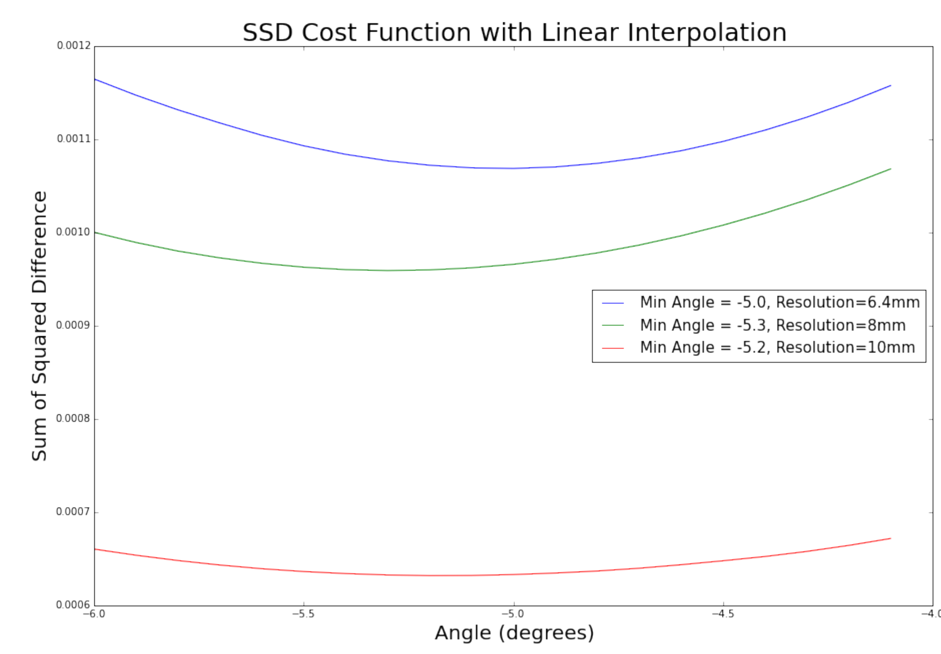

Figure 3. SSD comparison for trilinear interpolation

Conclusions

Compared with trilinear interpolation, Gaussian process is able to reduce interpolation error for 10mm and 8mm resolution. GP does so by integrating interpolation uncertainty into volume registration by using the covariance matrix to account for uncertainty estimates. However, there is no further improvement for volume with 6.4mm resolution.

Citations and Links

Wachinger C, Golland P, Reuter M, Wells W. "Gaussian Process Interpolation for Uncertainty Estimation in Image Registration." *Medical image computing and computer-assisted intervention: MICCAI . International Conference on Medical Image Computing and Computer-Assisted Intervention*. 2014;17(0 1):267-274.

Lingling Zi, Junping Du, and Qian Wang, "Frame Interpolation Based on Visual Correspondence and Coherency Sensitive Hashing," Mathematical Problems in Engineering, vol. 2013, pp. 1–11, 2013

School of Engineering and Applied Sciences • Institute for Applied Computational Science