Tagged MRI Analyses Using a Gabor Filter Bank

Zhen Qian ¹, Dimitris Metaxas ¹, Tushar Manglik ², Leon Axel ²
¹ Department of Biomedical Engineering, Rutgers, the State University of New Jersey
² Department of Radiology, New York University, School of Medicine

Background
Tagged cardiac magnetic resonance imaging is a well-known technique for non-invasively visualizing the detailed myocardium motion and deformation. In this project, our objective is using a tunable Gabor filter bank to preprocess and analysis tagged MR images. The results of our Gabor filtering will assist our higher level image processing tasks such as boundary segmentation, boundary tracking and tagging lines tracking.

Methods and Results
A Gabor filter is basically a Gaussian multiplied by a complex sinusoid. In 2D cases,
\[ h(x, y) = g(x', y') \cdot s(x, y) \]
where,
\[ g(x', y') = \frac{1}{2\pi\sigma_x\sigma_y} \exp\left[-\frac{1}{2} \left( \frac{x'^2}{\sigma_x^2} + \frac{y'^2}{\sigma_y^2} \right) \right] \]
\[ s(x, y) = \exp[-j2\pi(Ux +Vy)] \]
\[(U, V)\] are the 2D frequencies of the complex sinusoid, and its orientation is given by \( \phi = \arctan(V/U) \).

Figure 2: Real part of a Gabor filter in the spatial domain.

Because the input images are taken during the systolic process, the spacing between tagging lines would change, and no longer be parallel. As shown in figure 1. These changes in the spatial domain lead to corresponding changes in the frequency domain. The new \( U' \) and \( V' \) were specified as follows:
\[
U' = \Re\{ (U + iV) \cdot m \cdot \exp(i\cdot\Delta\phi + \omega) \} \\
V' = \Im\{ (U + iV) \cdot m \cdot \exp(i\cdot\Delta\phi + \omega) \}
\]
where, \( m, \Delta\phi \) and \( \omega \) are the magnitude, the angle, and the phase modulations respectively. We modulate \( m \) corresponding to the changes of tag spacing, and modulate \( \Delta\phi \) corresponding to the changes of the tag lines’ orientation. Phase angle \( \omega \) modulation represents the relative position of the current pixel with respect to the nearby tagging line.

1. Tagging Line Extraction
By convolving the input tagged MRI with an \( m \) and \( \Delta\phi \) tunable Gabor filter bank, we can enhance the tagging lines and extract them out, because at each pixel in the tagging lines, we tune the Gabor filter parameters to fit the local tag pattern well. The final results are combinations of the filtering results of each Gabor filter in the filter bank.

Figure 3: The Extraction results of figure 1. The myocardium contours are drawn manually for better readabilities.

2. Tagging Lines Removal
Phase angle \( \omega \) modulation represents the relative position of the current pixel with respect to the nearby tagging line. Tuning \( \omega \) makes the tag extraction operation also occur in regions between tagging lines. Thus by tuning all the three parameters of the Gabor filter, we can fill in the areas between the tagging lines, i.e., the tagging lines are removed and the tag-patterned areas are enhanced. Because after the initial tag modulation, the tag patterns in the blood are flushed out very soon, this tag removal method can enhance the blood-myocardium contrast and facilitate myocardium segmentation.

Figure 4: (b) is the tag-removed result of (a), (c) is the segmentation result derived from the tag-removed image.

3. Gabor Tracking
At each pixel, we apply our tunable Gabor filter bank and find out a set of optimal filter parameters that generate the strongest filter response. Figure 5 are parameter maps that consist of those optimal parameter values.

Figure 5: Maps of optimal parameter values.

The motion over time is given by:
\[
\Delta D = D_{\text{original}} \cdot \Delta \omega / (\pi \cdot m) \\
= D_{x,\text{original}} \cdot \Delta \phi_x / (\pi \cdot m_x) + D_{y,\text{original}} \cdot \Delta \phi_y / (\pi \cdot m_y)
\]
Because the input images are taken during the systolic process, the orientation image of the tagging lines can be obtained. The warm color means the orientation is from lower left to upper right; the cold color means the orientation is from upper left to lower right.

Figure 6: Gabor tracking result from time 0 to time 8. This method is implemented in our boundary tracking method.

4. 3D Extension
In 3D extension, we design the 3D Gabor filter based on the geometric characteristics of the tagging sheets.

Figure 7: Left is a 3D Gabor filter used in our experiment. Right is the result of the 3D tagging sheet extraction.

Reference: