EE678-Application Assignment
Tag Identification in Cardiac MRI using DWT

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Abstract

The heart is a spectacularly successful electromechanical pump, but its failure is the major cause of death in western and eastern world alike. In 2001, cardiovascular diseases (CVD) were the cause of death of 17 million people worldwide and 2 million people in India [1]. Many of these fatalities could be prevented if it would be possible to predict the condition of the heart, by measuring local myocardial motion. MRI is an imaging technique used primarily in medical settings to produce high quality images of the inside of the human body. The use of MRI in measuring cardiac motion is particularly important because MRI is the only modality capable of imaging detailed intramural motion within the myocardium in 3D. In order to track points in the myocardium, it is necessary to introduce “features” in the form of tags. Tags are temporary markers (like alternating dark bands) whose deformation follows the motion in underlying tissue. These tags are identified by a Fourier based method called Harmonic Phase (HARP) method. An innovative method has been presented to identify tags in the cardiac MR images using the DWT transform. The directional filtering property of the DWT has been made use of in identifying and extracting the tags.

Index Terms
Cardiac MR imaging, tagging, SPAMM, DWT, tag tracking.

I. INTRODUCTION

MRI can be used in the visualization of detailed cardiac anatomy, providing an accurate determination of regional wall thickness and muscle mass in the left ventricle. The use of MRI in measuring cardiac motion is important in pre-diagnosis of various cardiac ailments like coronary heart disease (CHD), ischemic heart disease (IHD) and myocardial infarct (MI) [2]. Analysis of these images involves separation of tags from the anatomic image. This is required for motion estimation because tags being the material property of tissue will deform along with heart motion. In HARP method, the Fourier spectrum of the tagged image is first obtained. A spectral peak is to be extracted from the spatially modulated magnetization (SPAMM) tagged cardiac MR images to obtain the Harmonic Phase (HARP) image. Ultimately, it becomes a problem to design a
two dimensional band pass filter to get the spectral information which facilitates estimation of non-rigid motion and deformation of heart. A novel tag identification procedure has been described which makes use of a Discrete Wavelet Transform (DWT) for extracting the spectral peak. A Hilbert transform based method is then used for obtaining the HARP images. It is important to consider the following points while extracting a spectral peak from the tagged MR images of heart.

Figure 1: Tagged MR images immediately after applying tags at end diastole and after 260 ms at near-end systole [3]

- Spectral energy belonging to a particular spectral peak of a Tagged MR image is spread over a significant region and it is hardly possible to isolate the region over which the spectral information is clearly present. Also, the geometry of the spectral spread depends upon the tissue motion. Hence, in the HARP method, designing an appropriate elliptical shape 2-D band pass filter is difficult because in a small region, the spectral information is incomplete and there is a loss of accuracy, whereas when it is too large it introduces artefacts.

- A major difficulty in tag identification is due to the DC peak that dominates other important peaks. This DC peak sometimes overlaps and hides the other spectral peaks that are corresponding to tagging lines. The information in a DC peak is the anatomic information and does not correspond to the tagging pattern. This justifies the need to eliminate the DC peak.

- The tag lines fade over the time frames and therefore extraction of all the spectral peaks lying in a particular direction can help in increasing the total energy belonging to the tag line pattern.
• If magnitude MR images of heart are used, the tag profile becomes rectified like a pattern and differs from sinusoidal pattern. However it reflects the periodicity of tagging lines. Exact wave shape of this pattern is however important for motion estimation.

• Directional filtering of tagged MR images with filters oriented along the tag direction can enhance the tag line along that direction and so, oriented filters can be used for separating tag lines in order to minimize the interference. Using this idea, a novel method for tag identification using the DWT based feature extraction has been described.

II. BACKGROUND THEORY

The 2-D DWT
The approach of one dimensional DWT for evaluating the DWT of two dimensional signals using the Mallat’s wavelet transform representation of an image is shown in Figure 2. It consists of coarse coefficients and detail coefficients.

The coarse and detail coefficients are obtained by Mallat’s method as shown in figure 3.
Two-Dimensional DWT

Decomposition step

Considering the particular property of the DWT to separate the coefficients into vertical, horizontal, diagonal along with the low pass information, it is possible to separate the tags from cardiac tagged MR image in two orthogonal directions. Further as one approaches higher scales, most of the tagging information goes into vertical, diagonal and horizontal coefficients and what remains is only the anatomic image in the low pass sub band. Anatomic residual information is not at all required for calculating the heart motion and deformation. Not only this, the DC peak that appears in the spectrum causes additional difficulty in spectral peak extraction. Therefore if this low pass information is discarded and inverse DWT is obtained, the reconstructed image will be free from the DC peak.

Mathematical Background of obtaining HARP image:

If \( p \) is a material point, then for a 2-D tagged image,

\[
I(p) = I_0(p) f(p; g_1) f(p; g_2)
\]
where \( I(p) \) is the intensity of point \( p \) after tagging, \( I_0(p) \) before tagging, and \( f(p,g) \) is the tagging pattern given by:

\[
f(p,g) = \sum_{n=0}^{N-1} a_n \cos(n g^T p)
\]

where \( a_n \) and \( g \) depend on tagging mechanism. The tagging pattern is introducing amplitude modulation of underlying signal intensity. So, a more convenient way of writing above equation is:

\[
I(p) = \sum_{k=1}^{K} I_0(p) c_k e^{j w_k^T p}
\]

where \( w_k \) is the location of spectral peaks in the Fourier space. \( K = (2N-1)^2 \) for 2D tagged images. So, for a MR image in frequency domain, we can write:

\[
I(y,t) = \sum_{k=1}^{K} I_k(y,t)
\]

where \( I_k(y,t) = D_k(y,t) e^{j w_k^T p(x(y),t)} \)

and \( D_k(y,t) \) is called the harmonic amplitude image, \( y \) is a point on image. So, a tagged image is sum of \( K \) complex images, called harmonic images, each corresponding to a distinct spectral peak identified by frequency vector \( w_k \). Most of the energy of \( I_k \) is concentrated, due to the nature of the LV motion, around the spectral peak located at \( w_k \). So a 2-D band pass filter centered around \( w_k \), is used to extract harmonic image. The harmonic image, \( I_k(y, t) \) that is now extracted is a complex image having magnitude and phase at each \( y \). The phase of \( I_k \) is an image (the harmonic phase image, HARP) given by:

\[
\phi_k(y,t) = w_k^T p(x(y),t)
\]

This image contains information about motion of tags and hence also of the underlying tissue motion.

### III. APPLICATION

#### 1. Eliminating DC peak using the DWT

A majority of energy that is lying under the DC peak of a tagged MR image can be extracted and removed by using the DWT expansion at different scales. After passing through the low pass filters successively the coarse image possess negligible information about tag lines[4]. Thus, if reconstruction is done using only the vertical, diagonal and horizontal components, it is possible to get only the tagging grid pattern, eliminating the
DC peak. Haar wavelets have been used to demonstrate this purpose. Figure 4 shows the spectrum of tagged image before and after extracting the DC peak using DWT decomposition (haar) at scale 2.

![Figure 4: 2-D FT of original MR image and 2-D FT of MR image after DWT filtering (dc peak removed)](image)

2. **HARP image using DWT**

The algorithm consists of the following steps [4].

- Decompose the MR image at scale ‘j’ using the DWT.

- To extract the vertical features only the vertical coefficients are considered during image reconstruction using the inverse DWT.

- The reconstructed image thus contains only the vertical tagging lines.

- For horizontal features similar reconstruction procedures can be followed with only horizontal coefficients at all the scales.

- The reconstructed image is complexified using the Hilbert Transform, to obtain a complex analytical image. The phase of this complex image is the angle image.

- A magnitude mask is obtained from the magnitude of the complexified image and applied to the angle to obtain final image with tags separated.
3. Results

Figure 5: Steps involved in DWT method

Figure 6: Tagged MR Image

Figure 6: Fourier Spectrum
Figure 7: Second Level decomposed images using Haar

Figure 8: Reconstructed image with vertical details and its spectrum. Reconstructed image with horizontal details and its spectrum.
ACKNOWLEDGEMENT

We thank Prof. V.M. Gadre for providing us with this exciting topic for our application presentation in EE678 Wavelets course. We also thank Amit Deshmukh for his valuable suggestions.

REFERENCES


