Medical Image Fusion Based on Discrete Wavelet Transform Using Java Technology

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Abstract. The importance of information offered by the medical images for diagnosis support can be increased by combining images from different compatible medical devices. The fusion process allows combination of salient feature of these images. In this paper we present different techniques of image fusion, our work for medical image fusion based on discrete wavelet transform and how we understand to integrate this process into a distributed application. The dedicated application considers Java technology for using its facilities as a future development, regarding a remote access mechanism.

Keywords. image fusion, wavelet transform, distributed application, multi-resolution decomposition.

1. Introduction

Medical imaging offers powerful tools that help physicians in the diagnosis process. Today, there are many medical modalities that give important information about different diseases. These equipments are accompanied by software programs which offer image processing facilities. Complementary information are offered by these modalities. For example, CT provides best information about denser tissue and MRI offers better information on soft tissue, [2]. These complementarities have led to idea that combining images acquired with different medical devices will generate an image that can offer more information than each other separate. In this way, the obtained image can be very useful in the diagnosis process, and that’s why the image fusion has become an important research field.

Not all hospitals or medical offices have software programs for image fusion. A remote access to such an application can be useful for physicians which want to use this method in the assisted diagnosis process. The fusion application can be a part of such a distributed application that runs in a medical center. Specialists situated at distance can access this application by Internet. They could load the images in the application and the result image will be displayed with a web browser.

There are some important requirements for the image fusion process, [5]:

- The fused image should preserve all relevant information from the input images
- The image fusion should not introduce artifacts which can lead to a wrong diagnosis

A very important step must be realized before fusion process, namely image registration. Multi-modality registration means the matching of the same scene acquired from different sensors. According to the matching features, the medical image registration process can be divided into three main categories: point-based, surface-based, and volume-based methods, [6].

Point-based registration involves the determination of the coordinates of corresponding points in different images and the estimation of geometrical transformation using these corresponding points.

Surface-based registration involves the determination of the surfaces of the images to be matched and the minimization of a distance measure between these corresponding surfaces.

Volume-based registration involves the optimization of a data quantity measuring the similarity of all geometrically corresponding voxel pairs, considering some predefined features.

Some of the image fusion methods have been introduced in the literature including simple pixel-by-pixel averaging using SNR (Signal to Noise Ratio) (ChungLi et al., 1999), wavelet transform methods (Hurt, 1994; Nunez, 1999),
Laplacian pyramid method (Burt and Adelson, 1983) and conditional probability network (Kiverri, 1998), [5].

2. Image fusion techniques

A dedicated application development could be based on different fusion techniques. The representative methods are presented in a brief mode, [6].

Fusion Using Logical Operators

This technique of fusion information uses logical operators. One image is the reference image and it is not processed. From the second image is established a region of interest and the information from these images are then combined. The simplest way to combine information from the two images is by using a logical operator, such as the XOR operator, according to the following equation:

\[ I(x, y) = I_A(x, y)(1 - M(x, y)) + I_B(x, y)M(x, y) \]  (1)

where \( M(x, y) \) is a Boolean mask that marks with 1s every pixel, which is copied from image \( B \) to the fused image \( I(x, y) \), [5].

Fusion Using a Pseudo-color Map

According to this fusion technique, the registered image is rendered using a pseudo-color scale and is transparently overlaid on the reference image. A pseudo-color map is defined as a correspondence of an \((R, G, B)\) triplet to each distinct pixel value.

For the fusion realized in Fig. 1, we have used six colors mapped on the all grayscale levels in the second image.

![Figure 1. Fusion using a pseudocolor map](image)

Clustering Algorithms for Unsupervised Fusion of Registered Images (FKM)

In this technique the fusion is realized by processing both registered images in order to produce a fused image with an appropriate pixel classification. The method uses the double histogram \( P(x, y) \) of the two registered images, which is defined as the probability of a pixel \((i, j)\) having a value of \( y \) in image \( B \), given that the same pixel has a value of \( x \) in image \( A \):

\[ P(x, y) = P(I_A(i, j) = x | I_A(i, j) = y) \]  (2)

The K-Means Algorithm

The K-means algorithm is a partitioned clustering algorithm, which is used to distribute points in feature space among a predefined number of classes. This algorithm is applied to the \( n \)-dimensional histogram of the images to be fused.

The algorithm could be employed to utilize information from pairs of images, such as CT, SPECT, MRI-T1, MRI-T2, and functional MRI, to achieve tissue classification and fusion.

The Fuzzy K-Means Algorithm

This technique is a variation of the K-means algorithm, with the introduction of fuzziness in the form of a membership function. The membership function defines the probability with which each image pixel belongs to a specific class. It is also applied on the \( n \)-dimensional histogram of the images to be fused. The FKM algorithm and its variations have been used for solving several types of pattern recognition problems.

Fusion to Create Parametric Images

This method is useful for fusion of information from a series of images of a dynamic study to classify tissues according to a specific parameter. The use of this technique leads to a parametric image, which visualizes pixel by pixel the value of the parameter useful for the diagnosis. The required classification is performed by thresholding the parametric image at an appropriate level.

Fusion at the Object Level

Fusion at the object level involves the generation of either a spatio-temporal model or a 3-D textured object of the required object. Segmentation and triangulation algorithms must be performed prior to the fusion process.

3. Image fusion algorithms

3.1. Algorithms of image representation

There are many algorithms for image fusion, [7]:

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- Image pyramid approaches: Laplacian pyramid, Gaussian Pyramid, ratio of low pass pyramid, contrast pyramid, Filter-Subtract- decimate (FSD) Pyramid, Morphological Pyramid, Gradient Pyramid ("Comparative Image Fusion analysis")
- Wavelet-based methods
- Total Probability Density Fusion
- Biologically-Inspired Fusion

Later improvements have been obtained in image fusion process with introduction of multi-resolution analysis (MRA), by employing several decomposition schemes, specially based on discrete wavelet transform, uniform rational banks, and Laplacian pyramids.

3.2. Discrete wavelet transform

Fusion based on transforms has some advantages over other simple methods, like: energy compaction, larger SNR, reduced features, etc. The transform coefficients are representative for image pixels.

Wavelets are used for time frequency localization, and perform multi-scale and multi-resolution operations. Discrete wavelet transform (DWT), transforms a discrete time signal to a discrete wavelet representation. It converts an input series $x_0, x_1, ..., x_m$ into one high-pass wavelet coefficient series and one low-pass wavelet coefficient series (of length $n/2$ each) given by the (3) formulas, [8]:

$$H_i = \sum_{m=0}^{k-1} x_{2i-m} \cdot s_m(z)$$
$$L_i = \sum_{m=0}^{k-1} x_{2i-m} \cdot t_m(z)$$

- $s_m(z)$ and $t_m(z)$ are called wavelet filters, $k$ is the length of the filter, and $i=0, ..., [n/2]-1$. In practice, such a transformation will be applied recursively on the low-pass series until the desired number of iterations is reached.

Image multi-resolution analysis was introduced by Mallat in the decimated case (critically sub-sampled), [9].

The DWT has been extensively employed for remote sensing data fusion. Couples of sub-bands of corresponding frequency content are merged together. The fused image is synthesized by taking the inverse transform. In literature are proposed fusion schemes based on ‘a trous’ wavelet algorithm and Laplacian pyramids (LP). Unlike the DWT which is critically sub-sampled, the ‘a trous’ wavelet and the LP are oversampled. For critically sub-sampled schemes, spatial distortions, typically ringing and aliasing effects may be present in the fused results and originate shifts or blur of contours and textures.

Image fusion is implemented by two-dimensional discrete wavelet transform.

The resolution of an image, which is a measure of amount of detail information in the image, is changed by filtering operations of wavelet transform and the scale is changed by sampling. The DWT analyses the image at different frequency bands with different resolutions by decomposing the image into coarse approximation and detail coefficients (Gonzalez and Woods, 1998).

![Image decomposition scheme using 2D DWT](image)

3.3. Image representation using DWT

On the previously registered images a transform is applied. This operation generates coefficients for images. A fusion rule has to be established and applied on these coefficients. The fused image is obtained using inverse transform.

Wavelet Image Representations

Each image is decomposed by 2 levels using discrete wavelet transform. At every level are obtained two sets of coefficients, approximation (LL) and detail (HL, LH and HH). (Fig. 2)
3.4 Fusion rules

Fusion rules determine how the source transforms will be combined:
- Fusion rules may be application dependent
- Fusion rules can be the same for all sub-bands or dependent on which sub-band is being fused

There are two basic steps to determine the rules, [4]:
- compute salience measures corresponding to the individual source transforms
- decide how to combine the coefficients after comparing the salience measures (selection or averaging)

Fig. 3 presents a general fusion process using multi-level image decomposition.

Figure 3. General fusion process

There are many rules for image fusion. Some of them are very simple, like: MIN, MAX, MEAN, which use the minimum, maximum and mean values of the transform coefficients, (Fig. 4), [3].

Other rules involve more complicated operations, like: energy or edge. For these methods have to be used spatial filtering, like Energy filter or Laplacian operator edge filter. The kernels for these two filters are presented in (4.a) and (4.b) respectively.

Energy filter kernel
\[
\begin{bmatrix}
0 & 1 & 0 \\
1 & 2 & 1 \\
0 & 1 & 0
\end{bmatrix}
\]

Laplacian operator edge filter kernel
\[
\begin{bmatrix}
0 & -1 & 0 \\
-1 & 4 & -1 \\
0 & -1 & 0
\end{bmatrix}
\]

4. Dedicated application for image fusion using discrete wavelet transforms

The input images to be fused are decomposed by forward wavelet transformation. Each image is decomposed into the same levels using a periodic discrete wavelet transform. The wavelet transform decomposes each image into low- and high-frequency sub-band images.

We have implemented a dedicated application for image fusion using DWT. The application uses Java technology, because we want to integrate it into a distributed process. The application will be able to be accessed in a remote mode by physicians. A previous work, [1] that allows image retrieving will be considered.

We have implemented 2 methods for multi-level decomposition of the image.

One of them realizes the processing of the image first on horizontal, then on vertical direction. At horizontal processing the pixels placed in the left vertical half of the result image are obtained by summing the two adjacent pixels from that row in source image, and the pixels of the right half are obtained by difference between the same pixels from source image. The process is similar for vertical processing. Fig. 5 presents the results of this decomposition on three levels.
In the other method to create four sub-images, we break the original image into 4 pixel blocks, 2 pixels to a side. If the original image has size $2^n \times 2^n$, we should have $2^{2n-2}$ blocks. For each block, the top-right pixel will go directly into the top-right sub-image. The bottom-left pixel goes directly into the bottom-left sub-image. And the bottom-right pixel goes into the bottom-right sub-image. So these 3 sub-images will look like a coarse version of the original, containing 1/4 of the original pixels. All 4 pixels of the block are averaged and placed into the top-left sub-image. So the top-left sub-image is effectively a scaled down version of the original image at 1/4 the original size, and it does not contain any of the original pixels itself, [11]. Fig. 6 shows this principle and Fig. 7 the result of such decomposition on one level.

The next step after decomposition of source images is the application of the fusion rule. We choose to use the maximum of the absolute value of the coefficients at every decomposition level. The result is then obtained using inverse discrete wavelet transform.

The application allows users to select two images from a directory, display them and then to render the fused image. The application can load even Dicom images, and obtain their fused image. For displaying Dicom images we have used the Pixelmed toolkit library, [10].

Fig. 8 displays the result of the fusion between CT and MRI images, using the MAX algorithm as a fusion rule, and two levels for images decomposition. The fusion algorithm is integrated into an application which also offers some facilities for image processing.
We have also tested the fusion using the MIN (Fig. 10) and MEAN (Fig. 11) algorithms, but the results are worse than that obtained with MAX algorithm (Fig. 9).

Figure 9. Fusion using MAX algorithm

Figure 10. Fusion using MIN algorithm

Figure 11. Fusion using MEAN algorithm

5. Conclusions and future work

The medical image fusion is a very important technique and there is a real interest in this kind of applications. There are many methods for realizing this purpose and they have to be studied to choose the better one to a dedicated domain.

Our application is intended to be useful for physicians who need to fusion multi-modality images for support in diagnosis. We will integrate the fusion process into a distributed application, [1]. In this way, the physicians would have access from remote locations, if they have Internet connection and an account created for this application. So, the physicians can do image fusion from their medical office or from home.

In the future, we want to integrate other techniques for fusion and testing it for different types of complementary medical images. We also want to develop methods for registration images from different medical modalities.

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7. References