

Techniques for Fusion of Multimodal Images: Application to Breast Imaging

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ABSTRACT

In many situations it is desirable and advantageous to acquire medical images in more than one modality. For example positron emission tomography can be used to acquire functional data while magnetic resonance imaging can be used to acquire morphological data. In some situations a side by side comparison of the images provides enough information, but in other situations it may be considered a necessity to have the exact spatial relationship between the modalities presented to the observer. In order to accomplish this, the images need to first be registered and then combined (fused) to create a single image. In this paper we discuss the options for performing such fusion in the context of multimodal breast imaging.

Index Terms— Visualization, Biomedical imaging, Biomedical image processing, Positron emission tomography, Magnetic resonance imaging, Biomedical nuclear imaging, Medical decision-making, Medical diagnosis

1. INTRODUCTION

Application of a multimodality approach is advantageous for detection, diagnosis, and management of many ailments. Obtaining the spatial relationships between the modalities and conveying them to the observer maximizes the benefit that can be achieved.

The process of obtaining the spatial relationships and manipulating the images so that corresponding pixels in them represent the same physical location is called registration. Combining the registered images into a single image is called image fusion.

The advantage of a fused image lays in our inability to visually judge spatial relationships between images when they are viewed side by side. Depending on background shades and colors, identical shapes and lines may appear to be different sizes [1]. The most obvious application is to combine a functional image that identifies a region of interest, but lacks structural information necessary for localization, with an anatomical image providing this information.

In this paper we examine the benefits of a multimodality approach in the context of breast cancer. We then briefly discuss a recently developed registration technique before launching into possible fusion options.

1.1. Multimodality Breast Cancer Imaging

Application of a multimodality approach is advantageous for detection, diagnosis and management of breast cancer. In this context, F-18-FDG positron emission tomography (PET) [2, 3], and high-resolution and dynamic contrast-enhanced magnetic resonance imaging (MRI) [4, 5] have steadily gained acceptance in addition to x-ray mammography and ultrasonography. Initial experience with combined PET (functional imaging) and x-ray computed tomography (CT, anatomical localization) has demonstrated sizable improvements in diagnostic accuracy, allowing better differentiation between normal (e.g. bowel) and pathological uptake and by providing positive finding in CT images for lesions with low metabolic activity [3].

As part of our work a method was developed for the coregistration of PET and MRI images, to provide additional information on morphology (including borders, edema, and vascularization) and on dynamic behavior (including fast wash-in, positive enhancement intensity, and fast wash-out) of the suspicious lesion and to allow more accurate lesion localization including mapping of hyper- and hypo-metabolic regions as well as better lesion-boundary definition. Such information might be of great value for grading the breast cancer and assessing the need for biopsy. If biopsy is needed, it could be precisely guided to the most metabolically active (i.e. most malignant) region.

2. IMAGE REGISTRATION

Since the breasts are entirely composed of soft tissue, they easily deform and require nonrigid registration. Physically-based deformable breast models are very difficult to implement because of complex patient-specific breast morphology and highly nonlinear and difficult to measure elastic properties of different types of tissues in the breast, as well as explicitly unknown boundary conditions [6]. The approach presented here for the nonrigid coregistration of multimodal images overcomes these difficulties because it does not require patient-specific breast morphology and elastic tissue properties.

Registration occurs as a two step process. During the first step displacement between corresponding fiducial skin markers (FSMs) is used to calculate a displacement field over the entire breast. The specially prepared FSMs are taped to predefined locations on the breast prior to data acquisition, and are visible in all modalities. A dense displacement field is estimated by first distributing the observed FSM displacement vectors linearly over the breast surface and then distributing throughout the volume. This process has been implemented using standard finite element

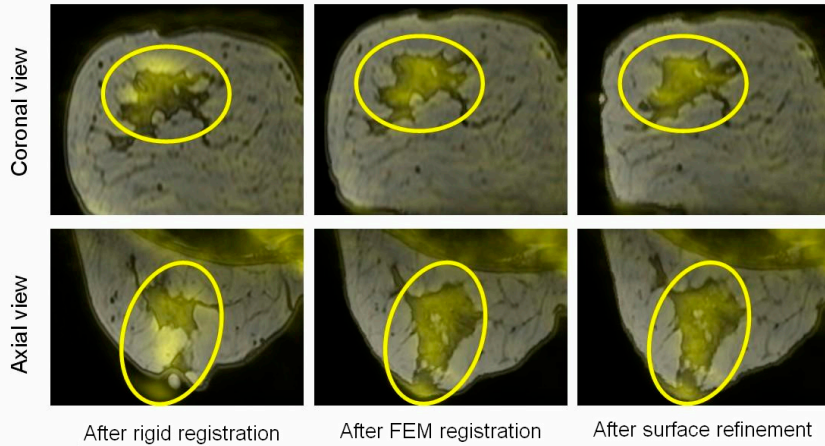


Fig. 1. Registered and fused PET and MRI breast images. Yellow: PET. Gray: MRI. The suspicious lesion area is circled.

method (FEM) software. Using the resulting displacement field we can warp the MRI image to the PET image (Fig. 1).

Since small registration errors still exist in regions away from the FSMs, a surface refinement process is performed. During this phase of registration a large number of corresponding surface points are identified on the warped MRI image and the CT image of the breast that is obtained just before PET (using a PET/CT scanner), and that is coregistered with the PET image. The displacement vectors found between the corresponding points in the MRI and CT images are then used to deform the mesh a second time. The displacement field provided by the mesh is then used to create the registered image (Fig. 1). More information about this registration process can be found in [7, 8]

3. FUSION TECHNIQUES FOR VISUALIZATION

Even when viewing the registered images side by side spatial relationships may be difficult to ascertain. A combined MRI/PET image has the benefits of directly showing the spatial relationships between the two modalities, increasing the sensitivity, specificity, and accuracy of diagnosis.

Several factors need to be considered when choosing a visualization technique. These include information content, observer interaction, ease of use, and observer understanding. From an information point of view it is desirable to maximize the amount of information present in the fused image. Ideally, the registered images would be viewed as a single image that contains all of the information contained in both the MRI image and the PET image. Limitations in the dynamic range and colors visible on current display devices, as well as limitations in the human visual system make this nearly impossible.

This loss of information can be partially compensated by making the fused display interactive. Some sort of control over the fusion technique can be provided which allows the observer to change the information that is visible in the fused display.

The design of this control is an important part of the fusion process. How simple is it to use the control? How much training is required? Do the display options offered by the control aid the observer or just complicate the observation process? How responsive is the control?

The last and perhaps the most important factor relates to the observers understanding of the fused volume. For example, radiologists understand what they are looking at when they examine a grayscale MRI image, or PET image. The variations in intensity and texture have meaning. In the ideal case the knowledge and experience the observer has in examining the individual modalities would be directly applicable to the fused images.

3.1. Color Overlay

One of the most common techniques used for the fusion of two images is the color overlay technique [9, 10]. In this technique one image is displayed semi-transparently on top of the other image. This can be implemented in many ways such as the addition of images, implementation of a 2D color table, or use of

the alpha channel.

In this paper it is implemented by performing a weighted averaging of the source images. Color tables are used to convert the grayscale MRI image and grayscale PET image to color images. We permit the weighting to be set, and the intensity of the fused image to be adjusted. Averaging causes a loss in contrast and a decrease in overall intensity, so the ability to scale the intensity of the fused image may be necessary. An example of an image fused using color overlay is Fig. 1. The MRI image is displayed using a grayscale color table and the PET using a yellow color table. The images are given equal weight and the resulting intensity is not being adjusted.

Other common color tables used include grayscale/hot-cold, and red/green. Study of the human visual system suggests that intensity should be used for the higher resolution image while color should be used for the lower resolution image. This is because the human eye is more sensitive to changes in intensity than changes in color [11]. The optimum color table is operator dependent, and care should be taken to select a color table that conveys the original intent of the image.

Weighting can be adjusted via a scroll bar. When the slider is on one side of the scroll bar the PET image is shown, when it is on the other the MRI. When the slider is set in between these extremes an image that is a linear combination of the PET and MRI is shown. For example if the scroll bar is set to 76% PET image and 24% MRI image, the displayed image can be calculated by multiplying the brightness adjustment by the weighted average of the source images ($0.76 \cdot \text{PET} + 0.24 \cdot \text{MRI}$). This equation would be used three times, once for each channel in the displayed image (red, green, blue), using the associated channel in each of the source images.

Color overlay is probably the most common technique used due to its simplicity. The controls are intuitive, and require little or no training or mathematical background. Depending on the choice of color it is easy to visually pick out the contribution from each of the source images in the resulting image, and convey the original meaning of those images to the user.

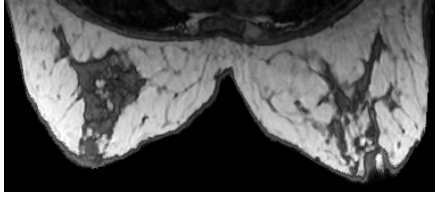


Fig. 2. Original MRI image.



Fig. 3. Original PET image.

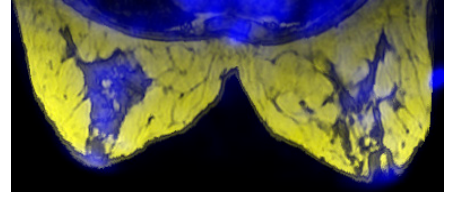


Fig. 4. Image created using color mixing fusion technique. Corresponding color table is shown in Fig. 5.

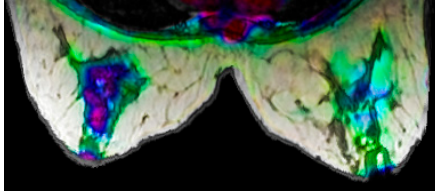


Fig. 6. Image created using HSL color space. Hue=PET, Saturation=CT, Lightness=MRI.

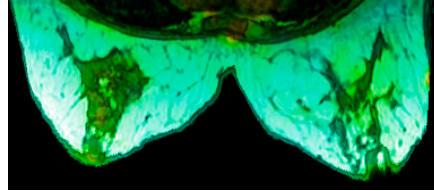


Fig. 7. Image created using HSL color space. Hue=PET, Saturation=constant, Lightness=MRI. Hue values are allowed vary from cyan to green to yellow.

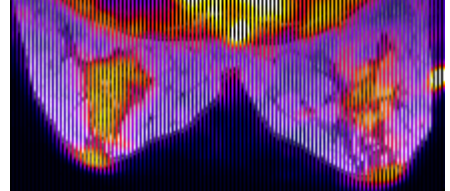


Fig. 8. Image created by interlacing PET and MRI volumes. PET image is displayed using a fire color table and MRI with a grayscale color table.

3.2 Color Mixing

Color mixing is a technique that can be used to take any number of one channel images (N) and create a fused RGB image. We perform channel mixing using Eq. 1. Here R, G, B represent the red, green, and blue channels in the displayed image respectively, S_i represents the intensity in the i^{th} source image, R_i, G_i, B_i are the weighting factors for the red channel, green channel, and blue channel. They determine the contribution of source i to each of the output channels.

$$\begin{pmatrix} S_1 & S_2 & \dots & S_N \end{pmatrix} \begin{pmatrix} R_1 & G_1 & B_1 \\ R_2 & G_2 & B_2 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ R_N & G_N & B_N \end{pmatrix} = \begin{pmatrix} R & G & B \end{pmatrix} \quad (1)$$

Let the source intensities be normalized from zero to one. Applying Eq. 1 is then equivalent to taking the intensity axis of source i and lying it along the line segment formed by connecting $(0,0,0)$ to (R_i, G_i, B_i) in the RGB color space. The output image is then formed by summing the projections of each of these onto the red, green, and blue axes.

This example includes two sources (Fig. 2 and Fig. 3) and six weights. The user can manually change the weightings matrix. Even though this is a powerful technique that provides a nearly infinite set of possible fused images it is not suitable for clinical use, since it may be difficult to predict how changing weights affects the fused image.

The best implementation of this method in clinical settings would involve a radiologist spending the time to select a small set of weighting matrices that produce useful fused images. Then in normal clinical setting the observer could be presented a list describing these matrices and the capability to easily switch between them, via a drop down list or similar control.

For the most responsive implementation, RGB Mixing can be implemented as a 2D look up table (LUT) once the weights have been selected. Fig. 4 is an example of an image produced this way, and Fig. 5 is the corresponding 2D LUT.

3.3 Use of Other Color Spaces

A powerful, yet more complex technique for the creation of fused images involves the use of different color spaces [11, 12, 13]. A few examples include CIE XYZ, CIE L*a*b*, HSV, and HSL. Each source grayscale image can be used as a channel in the color space. The resulting color image can then be converted to the RGB color space for display. For example if registered PET, CT, and MRI images are available, MRI can be used as the lightness, CT as the saturation, and PET as the hue (Fig. 6).

This technique is perhaps better suited for the fusion of three sources, but none the less can be used for the fusion of two. It can be done by using a source for more than one channel, or by setting the third channel to a constant (Fig. 7).

Care needs to be taken with selection of a color space and its implementation details. For example, when mapping a source to the hue channel, it is advisable to map the source intensities to a small range of angles. Mapping to all 360 degrees will result in drastic color changes, distorting or hiding the intensity changes in the channel, and creating false segmentation.

It has been suggested that varying hue from cyan to green to yellow gives good results, while using the red, purple, and blue hues gave false impressions of lower intensity values [12].

Of the techniques described in this paper, the use of other color spaces is the least intuitive. In particular, the conversion from other color spaces to RGB often fuses the sources in a complex, difficult to understand manor. As a result training will most likely be needed before implementation in a clinical setting.

3.4 Interlacing

Interlacing is a very common image fusion technique [1, 10, 14]. A simple implementation is to interleave the columns of pixels in the source images. For example the first column of the fused

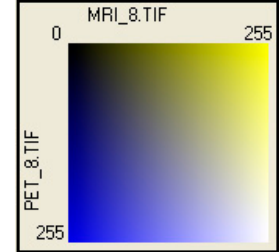


Fig. 5. Color table used to create Fig. 4.

image will be the first column of the MRI, the second column of the fused image will be the second column of the PET, and so on (Fig. 8). Independent color tables can be applied to the source images, and the observer should be given control of the source intensities. By adjusting the intensities of the source images the observer can bring the MRI or PET image out of the fused image as necessary.

Other interlacing options include interleaving the rows, or even every other pixel in the image. Adjusting the ratio of pixels given to the two modalities is another option for making one of the sources more prevalent. For example have two MRI rows followed by one PET row.

One of the largest drawbacks of an interlacing approach is the loss of spatial resolution. Discarding every other row or pixel, causes the contribution to the fused volume to have half of the resolution of the source. In the case of PET, which is magnified to be the same resolution as the MRI prior to fusion, this is a minor issue. However, the effect of this approach on the high resolution MRI should be considered.

This loss of resolution could be compensated for by doubling the size of the source images. This however is not always convenient. This issue has been addressed by performing the interlacing temporally rather than spatially. Rapidly alternating the images allows fusion to be performed within the eye, via residual images on the retina. Adjusting the intensity of the images, or their allotted display times will adjust their contribution to the fused image [14].

4. IMPLEMENTATION

Implementation of each fusion technique was done as a plug-in to KGB Fusion Viewer [15]. KGB Fusion Viewer was designed in house for the display and fusion of 3D medical images. It provides a framework that serves as the groundwork necessary for quick implementation of most fusion techniques.

5. CONCLUSIONS

By fusing the MRI and PET images a combined functional and morphological image is produced. We believe such an image will prove invaluable when detecting, grading the cancer, and assessing the need for surgical biopsy.

While the fusion techniques are presented here in the context of MRI and PET breast images, the same techniques can be used for fusion of other medical images. All of the techniques can be expanded for use with three or more sources.

The techniques reported are relatively simple to implement, and the difficulty is in choosing the most appropriate technique for a given diagnostic application, and colors that offer visual appeal, accurate representation of the source images, and improved diagnostic performance. In general there is not a scientifically optimum fusion technique, and the technique used should be governed by the diagnostic situation and the observer's experience, training, and preference.

Care should also be taken in preprocessing the images. Accounting for the high dynamic range in images, windowing, and intensity adjustments will have an important influence on the fused image.

The fusion techniques presented in this paper are currently being evaluated in the context of MRI and PET breast imaging. The results of the evaluation will be the focus of a future paper.

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