

# VISUALIZATION OF CHANGES IN MAGNETIC RESONANCE IMAGE DATA

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## ABSTRACT

Computer assisted image fusion provides an easy and accurate way to interpret and compare medical image pairs. Subjective expectations of human interpretator become less important when pixel-by-pixel-variations are calculated by computer. The estimation of sizes and locations of the differences also become more exact. We introduce new methods to visualize changes between images and present examples how they can be used to highlight contrast medium trace and to follow growth of brain tumor in MRI. The composite images created using these methods provide an illustrative way to discover faint or small-sized differences between separate volumes.

**Keywords:** angiography, image fusion, medical imaging, MRI, subtraction technique, tumor delineation

## 1 INTRODUCTION

The development of medical imaging techniques during last two decades has offered us improved views into the human body [Lent197, Seibe95]. This has resulted in development of non-invasive and less invasive diagnostics and treatment, resulting in cost savings and more comfort for the patients.

Sometimes the amount of the data provided to a doctor may contain too much information to control easily. Computer assisted image fusion is a method to com-

bine the information from various imaging modalities together. The fusion procedure consists of two steps; registration and image integration. The registration has been under intensive study and the methods have developed quickly [Strot94, Elsen93a, Viola95].

Roughly, medical image fusion may be divided in to two main classes [Elsen93b]. Intermodality fusion works with images whose modalities are not same. The main motivation for applying intermodality fusion is to add some features from another image to other image where those features

are not present. This can be done either by overlaying images or combine their information in order to create a new, usually color image which contains information about both originals.

Intramodality fusion requires that all the data originating from a single image formation technique. In this case separate image volumes may be used to improve resolution [Gosht96], or more commonly, to create a new series which maps the differences between original volumes.

This paper concentrates on presenting methods that perform data comparison for the medical images of the same modality. Because our main interest is in combination of anatomically consistent data points, the paper will not go into the details of the registration or it's error estimation.

In practice the comparison is usually done for volume data, but for clarity we speak about images and pixels for both two- and three-dimensional data.

Changes between consistent medical images taken at different moments of time may be natural, stimulated or artificial. Natural changes may be differences in composition (e.g. inflammation and necrosis) or various movements and deformations caused by normal body function (e.g. heart beating and ventilation). Stimulated changes contain treatment effects (e.g. shrinking of tumor due to radiation therapy), changes due to medical tests (e.g. stress tests and effects of hyperventilation) and externally stimulated changes (e.g. due to cooling or warming). If some substances which are normally not present are added, removed or moved between image acquisitions, differences in images are counted as artificial (contrast medium and instruments in images).

## 2 MEDICAL BACKGROUND

The comparison of anatomically consistent medical images contains lot of possibilities for misreading. Although subtraction imaging has been under intensive study we have not been able to find any work about visualization methods of subtraction images. In this article we demonstrate a few new ways to visualize differences between the images and ease the task of image interpretator in two common cases of clinical work:

### 1. Contrast medium highlight in MR images of the brain

Increased or decreased peripheral blood flow may give important information on certain diseases. The most common way to highlight areas of rapid capillary flow is to inject a bolus of contrast medium in vein from where it is carried with blood to the body area under interest. In current MRI subtraction imaging an image taken before the administration of contrast medium is subtracted from an image invested with the medium[Hajna95, Lee96]. All tissues containing the contrast medium remain visible but surrounding anatomy disappears. In some cases this is sufficient but sometimes doctors want to see the underlying anatomy and the changes caused by the contrast medium simultaneously.

### 2. MR observations of brain tumor growth

Follow-up studies are frequently performed for tumors and tumor residuals to observe their current status[Sarto99]. New MR images and consistent images taken in earlier follow-up session are usually compared by a radiologist, who detects possible growing or shrinking of the tumor as differences between images.

Perception of small changes which have appeared between controls is however difficult. The doctor has to spend time to look for the differences between images and compare their sizes.

Due to imperfect consistency of the images and subjectivity of interpretator, small differences in images may remain unnoticeable as well as some nonexistent changes become noticed. Additionally the quantity of the chance is difficult to estimate.

Marking the differences between the images to another of them may help the interpretator. It allows the user to examine only one sensibly constrained image instead of two separate images which anyway contain mostly identical information. Because highlighting of the differences is meticulous and time-consuming task for human, it is ideal to perform by the help of computers[Lee96].

### 3 METHODS

Suppose that we have two volume data sets representing same part of the body. Variation between the sets may come out of either real changes in target tissues or of external causes like movement of the target or changes in scanning device. Before we can visualize difference map we have to get rid of externally caused variations.

The major source of mistaken intensity variations is dislocalisation of the volumes. Various registration methods may be used to match them. Because the volumes in this case are of same modality it's possible to compare them directly to solve their consistency. That makes the registration step faster and easier to handle. For images in that article we have used user biased point pair consistency matching method, where user selects at least

four points in another volume and corresponding points in other volume. By help of the check points one of the volumes is reformatted so that calculated image slices from either of the volumes represent identical anatomical cross sections. We use trilinear interpolation to calculate the oblique cuts through the data set. Advantages of this kind of matching are the speed and possibility to control the process.

In addition to dislocalisation driven artifacts we are dealing with local intensity variations due to magnetic field inhomogeneity. In order to see veritable changes the intensity distributions of the images are adjusted in such a way that the intensities in the area of interest are equal in both images. Sometimes that may cause artificial differences at distance in the composite image. Those aberrations appear as overall, smooth transition to dominance of either of the original images.

Let a fused image ( $\mathcal{I}_f$ ) be any medical image which is created as a function of two existing anatomically consistent images of the same modality ( $\mathcal{I}_1$  and  $\mathcal{I}_2$ ). The fusion is performed pixel by pixel and we may formulate :

$$P_f = \mathcal{F}(P_1, P_2), \quad (1)$$

where  $P_1 \in \mathcal{I}_1$  and  $P_2 \in \mathcal{I}_2$  are pixels containing information about the same anatomic point. The fused pixel is denoted by  $P_f \in \mathcal{I}_f$  and the function  $\mathcal{F}$  describes any arbitrary fusion method.

The content of the pixel may be expressed in several ways. In gray scale images the pixel is defined by intensity  $I$ . RGB system defines the color using red  $R$ , green  $G$  and blue  $B$  channel intensities. Correspondingly In HSV system the color of the pixel is constructed by hue  $H$ , color saturation  $S$  and intensity value  $V$ . For simplicity the values of all these channels

$(I, R, G, B, H, S, V)$  are rescaled in to interval  $[0, 1]$ .

Using these notations the resulting pixel may be referred as  $P(I)$ ,  $P(R, G, B)$  or  $P(H, S, V)$ . We assume that original images  $\mathcal{I}_1$  and  $\mathcal{I}_2$  are gray scale images and we denote their gray scale pixel values with  $P_1$  and  $P_2$ .

We introduce some possible functions  $\mathcal{F}$  to visualize the difference between the pixels.

### 1. Difference Mapping

The most evident method to perform comparison is to arithmetically subtract the images from each others.

$$P_f(R, G, B) \Leftarrow \quad (2)$$

$$\begin{cases} R = (P_2 - P_1) & \text{if } P_1 < P_2 \\ G = (P_1 - P_2) & \text{else,} \end{cases}$$

where positive transitions are coded with red and negative with green. The intensity of the color is used as the indicator for the magnitude of the difference.

In the case where we are interested only in absolute differences we can calculate

$$P_f(I) \Leftarrow I = |P_1 - P_2|, \quad (3)$$

which codes the magnitudes of the changes to gray scale.

### 2. RGB color composition

If we want to preserve also the information on unchanged areas we may divide original images to separate RGB-channels of a new image:

$$P_f(R, G, B) \Leftarrow \quad (4)$$

$$\begin{cases} R = P_2 \\ G = P_1 \\ B = (P_1 + P_2)/2. \end{cases}$$

Thus the pixel from the image  $\mathcal{I}_1$  is saved in the red channel and the pixel from the image  $\mathcal{I}_2$  in the green channel. The blue channel is divided in order to produce some shade of gray where the values of the pixels are equal.

### 3. HSV color composition

Another way to combine the images without information loss is to code the pixel intensities in to hue, saturation and intensity values of the resultant.

$$P_f(H, S, V) \Leftarrow \quad (5)$$

$$\begin{cases} H = \mathcal{F}_1(P_2 - P_1) \\ S = |P_2 - P_1| \\ V = \max(P_1, P_2), \end{cases}$$

where  $\mathcal{F}_1$  is the function which defines the desired color palette. To attain hues from  $H_{min}$  to  $H_{max}$  we can formulate

$$\mathcal{F}_1 = \frac{P_2 - P_1 + 1}{2} \cdot (H_{max} - H_{min}) + H_{min}. \quad (6)$$

The color saturation depends on the magnitude of the change and the intensity value is the higher of the original intensities.

## 4 RESULTS

To illustrate the results of each method above, we have created two simple test images, which we have compared with each other (Fig. 1). The images are constructed in such a way that their combination contains all kind of intensity changes from decrease to increase.

Direct, color coded difference mapping (Fig. 2A) results in each level of difference being represented with an unique color. Dark color represents small changes

and bright color large changes in intensity. Red is used for increase of the intensity and green for decrease. The level of the initial intensity is impossible to see.

HSV color composition (Fig. 2B) provides unique color for each transition of intensity. In addition to the visualization of changes this also allows the visualization of the initial intensity. If the intensities of both images equal in some pixel, the combination of the pixels is encoded in their level of gray. Brighter color in resultant image tells about high intensity in the original images.

Like HSV color composition method, the RGB composition (Fig. 2C) also provides unique color for each intensity change. Due to average intensity in blue channel (Eq. 4) the overall appearance of the RGB composed image is quite flat and pastel.

An image fused using RGB or HSV composite methods gives the doctor an immediate view to the anatomy of the patient and the highlighted areas there. The interpretator may see without additional comparison where contrast medium has landed.

Fig. 3 presents the composite images when an image without contrast medium is subtracted from a contrast medium enhanced image, using methods introduced in section 3. In Fig. 4 same methods are applied to visualize the growth of brain tumor.

## 5 DISCUSSION

The direct mapping of difference gives us a good method to perceive both minimal and small-sized differences between the images (Fig. 3A and 4A). The method is also very sensitive to small errors originating from imperfect registration or calibration of the scanner (e.g. inhomogeneity of the MR magnetic field). Spatial cor-

relation between difference map and real anatomy is however difficult to estimate because the method hides all unchanged pixels by setting them almost black. This disadvantage may be helped by overlaying the result image on either of the originals. Unfortunately the perception of the small details in changes gets more difficult in that case.

RGB color composition method shows also in addition to the difference map, the anatomy common for both original images (Fig. 3B and 4B). The small-sized differences, especially in dark background, remain almost unseen. Overall appearance of the image is smooth, without steep gradients. Even weak differences are visible if they are wide enough.

Like RGB color composition method, also the HSV composition keeps surrounding anatomy untouched (Fig. 3C and 4C). In contrast to RGB composition this method shows small details well but disturbs to some degree areas of wide and weak difference. Changed borders and all kind of gradients are clearly seen. Another advantage of this method is possibility to select colors of the difference map freely.

In the composite fused images all the differences are directly visible and estimation of tumor growth is easy to perform. At the same time perception of possible new metastases becomes easier.

Appearance of RGB composite image seems to be slightly flatter than HSV composite image. Small details and borders of the intensified areas aren't seen as well. In comparison with situation of two separate images both of these methods however give superior results.

## 6 CONCLUSION

According to this study, creation and manipulation of the medical difference images is a compromise between good perception and accuracy. If the surroundings of the target are visually exact, sizes and shapes of the changed areas tend to drown out.

However, combined images introduce us a more objective method to estimate changes in medical image data. Effects of the interpreter's expectations become less important in a case where all real differences are mapped with a color. The amount of the change can be estimated directly from the fused image, without mentally swapping and measuring two separate images. In addition, unexpected changes further away from the expected area of interest are easier to notice.

The registration of the volume data with our current software is the most time-consuming part of the difference image creation. In comparison with some other needs for matching the task is still straightforward due to common modalities for both image series. If the patient hasn't moved between comparable shots, the images may even be compared without matching. In cases where poor registration leads to additional details in the computed difference image, the interpreter may easily notice the error and reject the conclusions about the image.

Additionally, partial volume effects caused by non-equivalence between imaging planes may give artifacts to combined images. That happens also if the original image series are obtained using different scanners or with another scanning parameters. Such errors are critical also when image combination is made in the human brain.

The real value of computer-made difference visualization of medical image data is difficult to estimate without clinical test-

ing. To find out the power of the methods we have started test series both in contrast medium highlighting and tumor growth visualization. We hope that we are able to prove some cases where these methods will help doctors to notice essential features in a large quantity of information.

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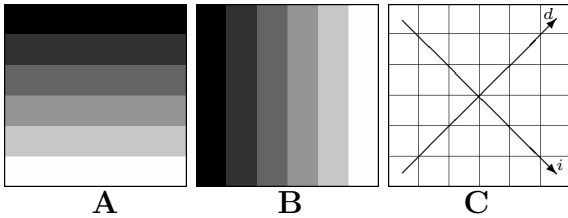
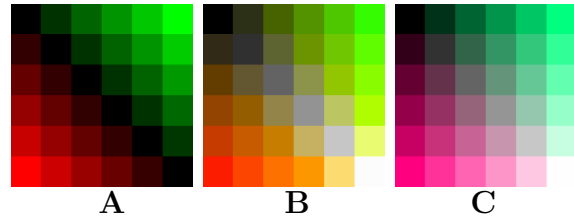
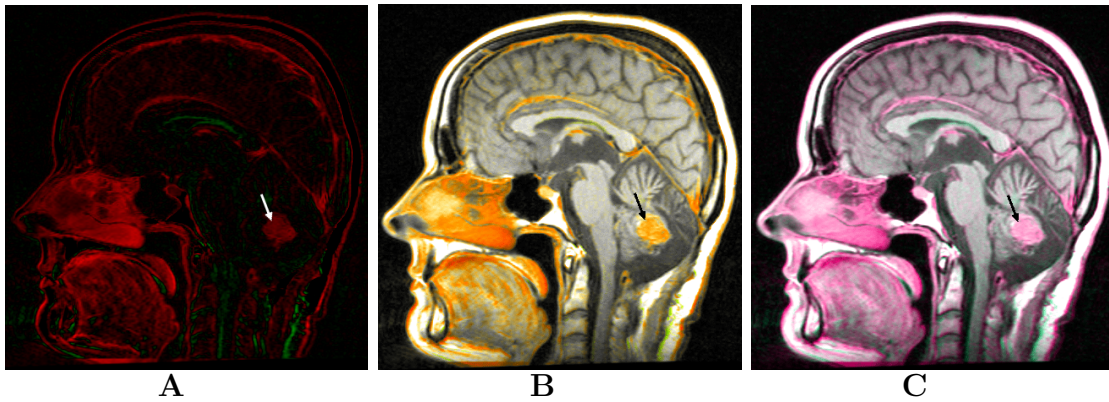


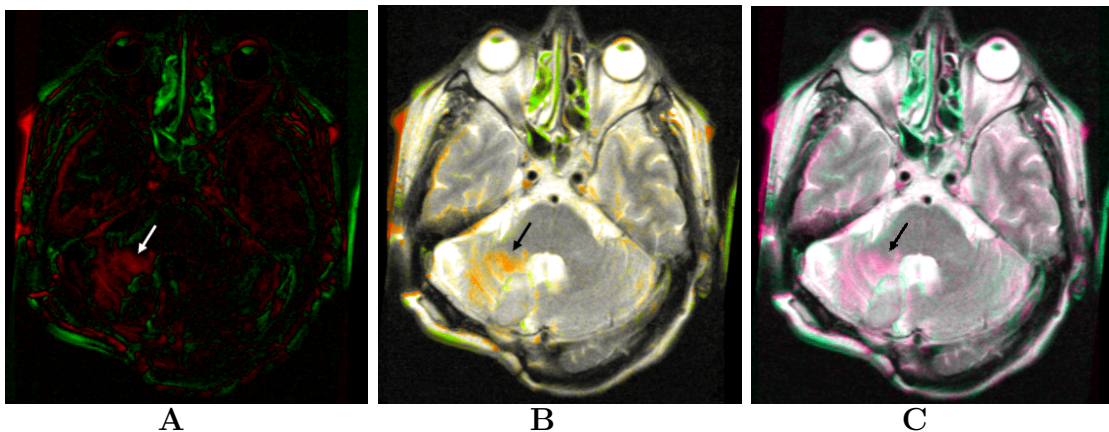
Figure 1: Difference coding for each method is demonstrated by fusing image with horizontal stripes **A** and image with vertical stripes **B**. In a resulting image **C** direction  $d$  represents changes from maximum decrease to maximum increase. Direction  $i$  represents the pixels where both original images have same intensity. The  $i$  goes from dark to bright.



Color Figure 2: Difference coding for direct difference mapping **A**, HSV color composition **B** and RGB color composition **C**.



Color Figure 3: Visualization of contrast medium using direct difference mapping **A**, HSV color composition **B** and RGB color composition **C**. The contrast medium is used to enhance tumor in cerebellum (arrow). Also nasal mucosa and cerebral membranes are enhanced due to their effective blood flow.



Color Figure 4: Visualization of tumor residual growth using direct difference mapping **A**, HSV color composition **B** and RGB color composition **C**.  $T_2$  intensity near the tumor has increased (arrow) giving tips on the growth of tumor. Highlights all over the images, especially in nasal area, are due to inhomogeneity in magnetic field, thick image slices and imperfect registration. Some small-sized changes may be drowned out by that noise.