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A Study On Image Fusion Techniques Of Complementary Medical Images

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Abstract: Image Fusion is a process of combining the relevant information from a set of images into a single image, where the resultant fused image will be more informative and complete than any of the input images. A very important step must be realized before fusion process, namely image registration. Image registration is a process of aligning two images acquired by same/different sensors, at different times or from different viewpoint. A goodregistration is compulsory for a good fusion. This paper presents a detailed study on several image fusion techniques as well as image registration techniques.

Keywords: Modalities, Image Fusion, Image Registration, Complementary Images, PET, MRI, CT, SPECT

I. INTRODUCTION

Medical imaging offers powerful tools that help physicians and surgeons 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 the modalities CT, MRI, PET, SPECT[1].Medical image fusion helps the radiologist for accurate diagnosis and for radiation treatment of the patients. As these images are interpreted separately by different clinical expertise, it may lead to misinterpretations, especially in the case of small tissue structures. For example, the PET image gives the functional information. It has low spatial resolution. Radiologist need to interpret the PET and MRI images during a clinical round for accurate diagnosis. Thus, the fusion of the PET and MRI images are necessary and it offers higher diagnostic accuracy [2]. Similarly, CT provides best information about denser tissue and MRI offers better information on soft tissue. 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 [1].

Image processing is not only used in analyzing an image but also for comparing or combining information given by different images. Thus image registration is one of the fundamental tasks within image processing.

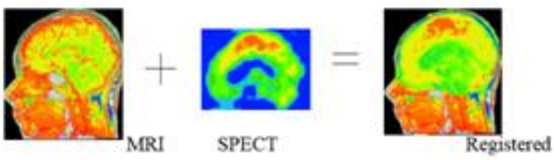
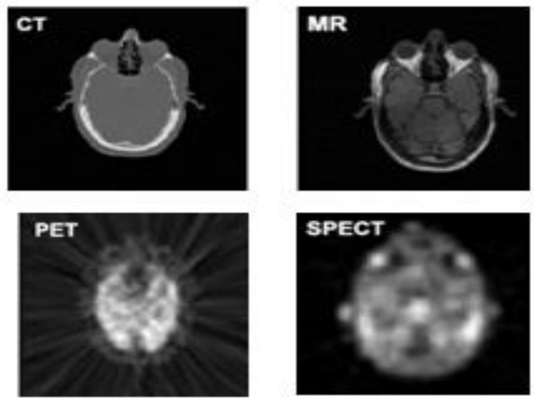


Image registration is the process of spatially aligning two or more images of the same scene, possibly recorded at different moments in time[3].In this paper, various Image Registration techniques and various Image Fusion methods are analyzed.

II.MODALITIES

Computed Axial Tomography (CT) scan, combines special x-ray equipment with sophisticated computers to produce multiple images or pictures of the inside of the body. The cross-sectional images of the area being scanned can then be examined on a computer monitor or be printed. CT scans of internal organs, bones, soft tissues and blood vessels can provide more details than a regular x-ray exam.



Magnetic Resonance Imaging (MRI) uses a magnetic field from super-cooled magnets to distinguish more accurately between healthy and diseased tissues. A MRI provides much greater contrast between the different soft tissues of the body than the CT scan. Using magnetic and radio waves, means no exposure to radiation. An MRI provides clear pictures of the body parts that are surrounded by bone tissue, so the MRI is very useful for examining the brain and spinal cord. A CT scan can only show pictures horizontally, while the MRI can scan from almost every angle with more detail.

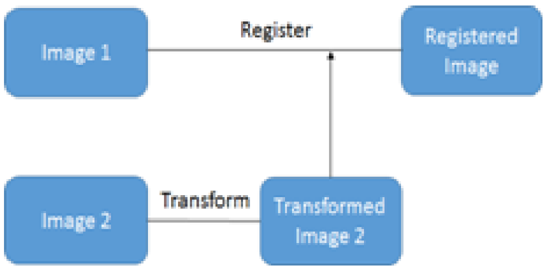
Positron Emission Tomography (PET) scan provides images on the function of a tissue rather than a static image like any x-ray. PET scan helps physicians locate the presence of any cancers or infections anywhere in the body. During the PET scan, glucose is injected into the body and taken up by cancer cells. The PET scan can detect any spread of cancer in the body. The amount of radiation exposure is minimal and the radioactive glucose is rapidly excreted from the body.

Single Photon Emission Computerized Tomography (SPECT) scan, analyzes the function of your internal organs. It is a type of nuclear imaging test that uses a radioactive substance and a special camera to show pictures of your organs. A SPECT scan produces 3-D images that show how your organs work. The scan is used primarily to view how blood flows through arteries and veins of organs such the heart and brain.

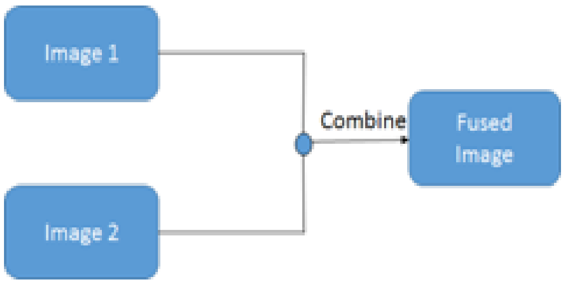
III. REGISTRATION VERSUS FUSION

The two stages of any image fusion method are (a) image registration and (b) fusion of relevant features from the registered images. The registration of the images requires a method to correct the spatial misalignment between the different image data sets that often involve compensation of variability resulting from scale changes, rotations, and translations. Image fusion is the process of combining multiple input images into a single composite image. [8]

Registration: consists in computing the geometrical transformation between two data sets. A good registration is mandatory for a good fusion.



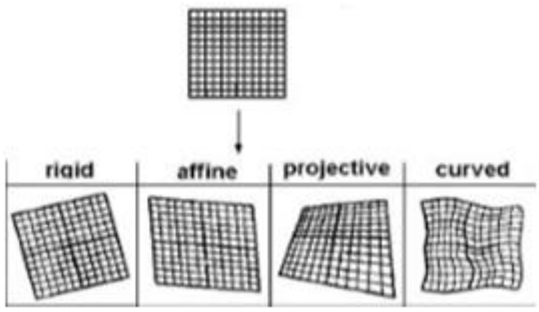
Fusion: consists in putting together information coming from different sources/data. This transformation is used to resample one data set.



IV. REGISTRATION

The purpose of registration is to compute the transformation that allows to superimpose two images. The Nature of transformation are

a. Rigid - An image coordinate transformation is called rigid, when only translations and rotations are allowed.
b. Affine - An image coordinate transformation is called affine if the transformation maps parallel lines onto parallel lines it is called affine.
c. Projective - If it maps lines onto lines, it is called projective.
d. Curved - If it maps lines onto curves, it is called curved or elastic. [4]



V. REGISTRATION ALGORITHMS

Image registration algorithms can be classified as

a. Area based methods
b. Feature based methods.

a. ***Area based methods*** are preferably applied when in images prominent details are absent and distinctive information is provided by gray levels rather by local shapes and structure.[5] Area-based methods put emphasis rather on the feature matching step than on their detection. No features are detected in these approaches.[9]

b. ***Feature based*** matching methods are applied when local structural information carried by image intensities are more.[5] This method is based on the extraction of salient structures–features—in the images. Significant regions, lines or points are understood as features here. They should be distinct, spread all over the image and efficiently detectable in both images. They are expected to be stable in time to stay at fixed positions during the whole experiment.[9] According to the matching features, the medical image registration process can be divided into three main categories: [1]

a. Point-based
b. Surface- based
c. Volume-based methods

a. ***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.

b. ***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.

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

VI. IMAGE FUSION

Image Fusion is a process of combining the relevant information from a set of images into a single image, where the resultant fused image will be more informative and complete than any of the input images.

There are some important requirements for the image fusion process,

a. The fused image should preserve all relevant information from the input images.
b. The image fusion should not introduce artifacts which can lead to a wrong diagnosis.[1]

The objective in image fusion is to reduce uncertainty and minimize redundancy in the output while maximizing relevant information particular to an application or task. [7]

VII. FUSION METHODS

There are various methods that have been developed to perform image fusion. Some well-known Image Fusion methods are:- [6]

a. Intensity-Hue-Saturation(IHS) transform
b. Principal component analysis (PCA)
c. Simple Average Method
d. Simple Maximum Method
e. Simple Minimum Method
f. Multi scale transform based fusion:-
a) High-pass filtering method
b) Pyramid method:-
(a). Gaussian
(b). Laplacian
(c). Ratio
(d). Contrast
(e). Filter Subtract Decimate (FSD)
(f). Morphological
(g). Gradient
c) Wavelet transforms:-
(a). Discrete Wavelet Transforms
(b). (DWT)
(c). Stationary Wavelet Transforms
(d). Multi- Wavelet Transforms
d) Curvelet Transforms

A. HIS:

The IHS technique is a standard procedure in image fusion. It was based on the RGB true color space. It offers the advantage that the separate channels outline certain color properties, namely intensity (I), hue (H), and saturation (S). [10]

B. Principal Component Analysis (PCA):

Principal Component Analysis is a subspace method, which reduces the multidimensional data sets into lower dimensions for analysis. This method determines the weights for each source image using the eigen vector corresponding to the largest eigen value of the covariance matrix of each source image. [6,11]

C. Simple Average Method:

In this method the resultant fused image is obtained by taking the average intensity of corresponding pixels from both the input image

F(i,j) = $\frac{A(i,j)+B(i,j)}{2}$

A(i,j), B(i,j) are input images and F(i,j) is fused image. [6,11]

D. Simple Maximum Method:

In this method, the resultant fused image is obtained by selecting the maximum intensity of corresponding pixels from both the input image.

$$F(i,j) = \sum_{i=0}^{m} \sum_{j=0}^{n} MaxA(i,j)B(i,j)$$

A(i,j), B(i,j) are input images and F(i,j) is fused image. [6,11]

E. Simple Minimum Method:

In this method, the resultant fused image is obtained by selecting the minimum intensity of corresponding pixels from both the input image

$$F(i,j) = \sum_{i=0}^{m} \sum_{j=0}^{n} MinA(i,j)B(i,j)$$

A(i,j), B(i,j) are input images and F(i,j) is fused image.[6,11]

F. High-pass Filtering Method:

a. Pyramid Method:

An image pyramid consists of a set of low pass or band pass copies of an image, each copy representing pattern information of a different scale. The basic idea is to construct the pyramid transform of the fused image from the pyramid transforms of the source images, and then inverse pyramid transform is performed to obtain the fused image. [12]

b. Gaussian Pyramid:

The Gaussian pyramid is a sequence of images in which each member of the sequence is a low pass filtered version of its predecessor [13].

c. Laplacian Pyramid:

Laplacian pyramid of an image is a set of bandpass images, in which each is a bandpass filtered copy of its predecessor. Bandpass copies can be obtained by calculating the difference between lowpass images at successive levels of a Gaussian pyramid [13].

d. Ratio Pyramid:

Ratio of Low Pass Pyramid is another pyramid in which at every level the image is the ratio of two successive levels of the Gaussian pyramid [13].

e. Contrast Pyramid:

Contrast Pyramid is similar to the ratio of Low Pass Pyramid approach. Contrast itself is defined as the ratio of the difference between luminance at a certain location in the image plane and local background luminance to the local background luminance. Luminance is defined as thequantitative measure of brightness and is the amount of visible light energy leaving a point on a surface in a given direction. [13]

f. Filter-Subtract-decimate (FSD) Pyramid:

Filter-Subtract-decimate (FSD) Pyramid technique is a more computationally efficient variation of the Gaussian Pyramid [13].

g. Morphological Pyramid:

Morphological Pyramid techniques introduced by Burt and Adelson etc. typically use low or bandpass filters as part of the process. These filtering operations usually alter the details of shape and the exact location of the objects in the image. This problem has been addressed by using morphological filters to remove the image details without adverse effects [13].

h. Gradient Pyramid:

Gradient Pyramid of an image is obtained by applying gradient operators to every level of its Gaussian pyramid G.

The gradient operators are used in the horizontal, vertical, and 2 diagonal directions. [13]

i. Discrete Wavelet Transform Method(DWT):

Wavelet transforms are multi-resolution image decomposition tool that provide a variety of channels representing the image feature by different frequency subbands at multi-scale.When decomposition is performed, the approximation and detail component can be separated 2-D Discrete Wavelet Transformation (DWT) converts the image from the spatial domain to frequency domain. The image is divided by vertical and horizontal lines and represents the first-order of DWT, and the image can be separated with four parts those are LL1, LH1, HL1 and HH1. [6,11]

j. Stationary Wavelet Transform:

The Discrete Wavelet Transform is not a time invariant transform. The way to restore the translation invariance is to average some slightly different DWT, called the stationary wavelet transform (SWT). It does so by suppressing the down-sampling step of the decimatedalgorithm and instead up-sampling the filters by inserting zeros between the filter coefficients.

Stationary Wavelet Transform (SWT) is similar to Discrete Wavelet Transform (DWT) but the only process of down-sampling is suppressed that meansthe SWT is translation-invariant.

k. Multiwavelet Image Fusion:

The operational procedure for the multiwavelet based image fusion approach is now summarized as follows: 1. The two input images are registered initially. 2. Each input image is analyzed and a set of multiwavelet Coefficients are generated. 3. The maximum frequency fusion rule or any other rule (Minimum, Average, PCA and Laplacian pyramid) is used for the fusion of the wavelet coefficients. 4. The inverse multiwavelet transform step is performed to obtain the fused image. [12]

l. Curvelet Image Fusion Method:

The algorithm for fusing images using the Curvelet transform is explained as follows: 1. The two input images are initially registered. 2. Each input image is then analyzed and a set of Curvelet coefficients are generated. 3. The maximum frequency fusion rule or any other rule (Minimum, Average, PCA and Laplacian pyramid) is used for the fusion of the Curvelet coefficients. 4. Finally the Inverse Curvelet transform (ICVT) step is performed to obtain the fused image. [12]

VIII. APPLICATION DOMAINS

A. Brain:

Brain is one of the important organs that have been subjected to a wide range of medical image analysis and research. The imaging studies reveal several important pieces of information about the brain which are otherwise not visible to human sensory mechanisms. [8]

B. Breast:

The breast has been subject of several studies due to the high rates of breast cancer in women. The most commonly used modality for breast studies is mammogram followed by MRI and/or CT. The combinations of PET and X-ray computed tomography has shown significant improvements in diagnostic accuracy, allowing better differentiation between normal and pathological uptake. [8]

C. Prostate:

Prostate is another organ that has been studied using multi-modal medical images. There exists a range of techniques and studies on prostrate based image fusion, that often face the challenge deformation of prostrate in multi-modal imaging setups [8]

D. Lungs:

Lung is a vital organ that undergoes direct contact with environment through the air intake and is the main part of respiratory system. Lungs are prone to damage from pollutants and viruses. The imaging of the lungs can often reveal several details that reflect the condition of the internaltissues. The ability to distinguish a damaged tissue, cancerous tissue and a healthy tissue is not an easy task in early diagnosis. Image fusion techniques have been shown to improve the diagnostic performance and screening, and especially improve the clinical monitoring outcomes. [8]

E. Liver:

The Liver is another vital organ that is being increasingly studied using images, and the complexity of the liver tissue makes the medical imaging studies challenging. The registration and fusion of liver images for medical diagnosis is a task of primary importance. [8]

F. Spinal Cord:

Spinal cord injury is usually the result of an accident (for example, motor vehicle accident, fall, sports injury) or acts of violence such as gunshot wounds. It can also be caused by surgical complications or by disease. The combinations of CT and MRI has been used to improve the diagnostic accuracy.

IX. COMPARISON OF DIFFERENT IMAGE FUSION TECHNIQUES

Various Image Fusion Techniques' advantages and disadvantages are compared.They are given in the Table given below.

Table: 1

Method	Advantage	Disadvantage
Simple Average	Simplest method of image fusion in implementation.	Resultant fused image is not clear
Simple Maximum	Resulting in highly focused image output obtained from the input image as compared to average method.	Pixel level method are affected by blurring effect which directly affect on the contrast of the image
PCA	PCA transforms number of correlated variable into number of uncorrelated variables	May produce spectral degradation.

Pyramid Methods	Inferior in Visual Quality, Produce sharp and high contrast images	In terms of complexity and real-time it is not good enough and to be improved.
Wavelet	Minimizing the spectral distortion. It also provide better signal to noise ratio than pixel based approach.	Final fused image have a less spatial resolution.
Curvelet	Solves the problem of blurring of edges and details in wavelet image fusion.	Weakens its singular point, has no good performance of the local variation of the image.

X. CONCLUSION

This study tried to give a first perfective and a methodology to determine what fusion methods and register methods should be used under which circumstances. In this paper a general method of Image Registration and Image Fusion techniques are thoroughly reviewd. After analyzing these methods, it was realized that a robust and generic method was needed to register and fuse complementary, multi modal medical images.

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