Texture Based Image Segmentation and analysis of medical image

1. The Image Segmentation Problem

Dealing with information extracted from a natural image, a medical scan, satellite data or a frame in a video sequence is the purpose of image analysis. In the real world, the stimulus that is received by the retina is perceived as whole and complete information. Between the electromagnetic reception and the perception, physiological and neurological processes construct the final perception and analysis of the image. In fact vision is composed of many interacting components including analysis of color, texture and shape, the whole conducted by prior knowledge of the human brain. Computer vision aims at getting the same result as human perception. The computer interface receives the image as a matrix of pixels/voxels and several levels of processes are involved to get, when it is possible, the same result as human analysis. The collection of processes involved in the visual perception are usually hierarchically classified as belonging to either low level vision or high level vision. High level vision consists of the interpretation of the image following some rule or prior knowledge. In low level vision, image processing is performed to extract some visible physical properties in the image such as shape and boundaries or to improve the quality of the image. In this thesis we will be dealing with **image processing** and more precisely with the **image segmentation task**. The objective of segmentation methods is to determine a partition of an image into a finite number of semantically important regions such as anatomical or functional structures in medical images or objects in natural images. The segmentation task has been studied for several decades; however it is still a challenging task. This task is essential in many applications including face detection in video sequences, changes detection in satellite images, anatomical or functional object extraction in medical images or object extraction in natural images.

My thesis work proposes solutions to the image segmentation problem in well established mathematical frameworks, i.e. statistical model, multi resolution model and morphological models. The image is defined in a continuous space and the segmentation problem is expressed through a functional or energy optimization. Depending on the object to be segmented, this energy definition can be difficult; in particular for objects with ambiguous borders or objects with textures. For the latter, the difficulty lies already in the definition of the term texture. The human eye can easily recognize a texture, but it is quite difficult to find words to define it, even more in mathematical terms. This is why we are first interested in the extraction of texture features that is to say, finding one representation that can discriminate a textured region from another. The usefulness of the segmentation is ultimately dependent on the features used for the annotation of data and its efficiency is dependent on the invariance and robust properties of these features. For texture based features an important form of invariance is rotational invariance. **This work describes effective and novel texture characterization and rotationally invariant texture characterization techniques using wavelet decompositions.** However, watershed segmentation is often not effective for textured image regions that are perceptually homogeneous. **In order to properly segment such regions the concept of the "texture gradient" is implemented using a dual tree complex wavelet packet transform. A novel marker location algorithm is subsequently used to locate significant homogeneous textured or non textured regions. A novel flooding algorithm is used for implementing the marker driven watershed transform to enable proper segmentation of the identified regions.**

2. Motivations and Contributions of this Thesis

The goal of this thesis is to study the problem of image segmentation and to propose algorithms to solve it. Among the various strategies available for achieving image segmentation task, morphological methodology is the one that has been chosen to introduce new algorithms. The principal reason is that such approach offer a rigorous mathematical framework. Moreover being in the continuous space, the pixel resolution is not a limit. The segmentation method that we will propose should be general enough to handle any kind of images including images with textures.

When we tackle the texture image segmentation problem, the problem of extracting pertinent features arise naturally. **Our first motivation is to define effective and novel texture characterization and rotationally invariant texture characterization techniques using wavelet decompositions.** This feature descriptor will be integrated in the segmentation framework. **This brings us to the second motivation which is a segmentation framework for texture images.** The segmentation method offer the comfort of a totally user independent automatic process. **We are also motivated by the use of statistical properties as well as directional properties extracted from textures and appropriate classification methodologies on the object to segment.**

Therefore, the main **contributions** presented in the thesis are:

- **We developed effective and novel rotationally invariant texture characterization techniques using dual tree complex wavelet packet transform which is found to outperform the existing spatial-frequency methods like Discrete Wavelet filters, Complex Wavelet filters, Gabor filters etc.**

- **The concept of Texture Gradient is used for texture characterization to account for images with textured and non-textured regions. This is found to give effective segmentation for artificial and natural texture images.**

- **A novel algorithm for creation of marker image is proposed and used for the segmentation stage. This is found to give good flexibility in controlling the extent of segmentation required.**

- **Proposed a novel algorithm based on repeated sequential scan for flooding from minima in association with watershed segmentation. This algorithm is found to outperform the existing flooding algorithms based on FIFOs and connected component labeling.**

- **We developed alternate segmentation strategies based on statistical as well as spatial frequency descriptor of Gabor filter and clustering methodologies and these have been used for comparison of the results obtained with the methodologies we proposed earlier.**

3. Literature review

Texture based image segmentation is an area of intense research activity in the past few years and many algorithms were published in consequence of all this effort, starting from simple thresholding method up to the most sophisticated random field type method. Recent approaches to texture based segmentation are based on linear transforms and multiresolution feature extraction [1], Markov random field models [2, 3], Wavelets [4-6] and fractal dimension [7].

Segmentation methods are based on some pixel or region similarity measure in relation to their local neighborhood. These similarity measures in texture segmentation methods use some textural spatial-spectral-temporal features such as Markov Random field statistics [8-10], co-occurrence matrix based features [11], Gabor features [12], local binary pattern[13], and many others.

4. Texture Gradient Based Watershed Segmentation

The aim of image segmentation is the domain independent partition of the image into a set of regions, which are visually distinct and uniform with respect to certain properties such as gray-level, texture or color. Two of the basic approaches for image segmentation are region and boundary based. These methods are based on two basic properties of pixels in relation to their local neighborhood: similarity and discontinuity. Pixel similarity gives rise to region-based methods whereas pixel discontinuity gives rise to boundary-based methods. In this work we attempt to use the property of ***Texture*** for assessing the similarity between regions.

A multitude of texture analysis techniques have been developed over the last two decades that have attempted to effectively represent image texture content. These techniques can be separated into or combined from statistical, stochastic, spatial-frequency, structural and fractal methods [14]. We adopt the spatial-frequency method based on wavelets for texture analysis. Although originally formulated for the continuous one dimensional case, Mallat [15] was able to generalise wavelet analysis to the two dimensional discrete case necessary for image analysis (DWT). This method uses a pair of *x-y* separable high and low pass filters within a tree structure to decompose the image into orientation and scale sensitive collections of wavelet coefficients known as subbands.

Many different methods have been proposed for extracting texture features from wavelet decompositions. Simple energy measures from each subband within a dyadic decomposition can be used very effectively to classify textures.

4.1 The Complex Wavelet Transform

A major problem for the DWT is their lack of directionality and shift invariance. Therefore small shifts in the input signal can cause large variations in energy across the subbands at different scales. Kingsbury [16] suggested that both of the above problems can be solved effectively by the Complex Wavelet Transform (XWT).

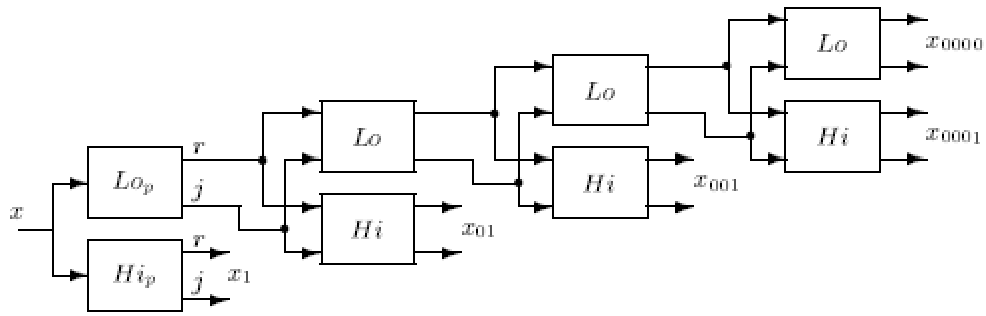

Fig.1: Four levels of the complex wavelet tree for a real 1-D input signal x. The real and imaginary parts (r and j) of the inputs and outputs are shown separately

The structure of the complex wavelet transform is as shown in Fig 1 and the XWT filters have complex coefficients and generate complex output samples. For many applications it is important that the transform be perfectly invertible. Unfortunately it is very difficult to design an inverse transform based on complex filters of the type given above.

4.2 The Dual Tree Complex Wavelet Transform

To overcome this, Kingsbury [17] proposed a *dual-tree* implementation of the XWT (DT XWT) which added perfect reconstruction to the other attractive properties of complex wavelets as shift invariance, good directional selectivity, limited redundancy and efficient order-N computation. It uses two trees of real filters to generate the real and imaginary parts of the wavelet coefficients separately. The two trees are shown in Fig.2 for 1D signals. Even though the outputs of each tree are downsampled by summing the outputs of the two trees during reconstruction we are able to suppress the aliased components of the signal and achieve approximate shift invariance. This operation results in six complex high-pass subbands at each level and two complex low-pass subbands on which subsequent stages iterate in contrast to three real high-pass and one real low-pass subband for the real 2D transform.

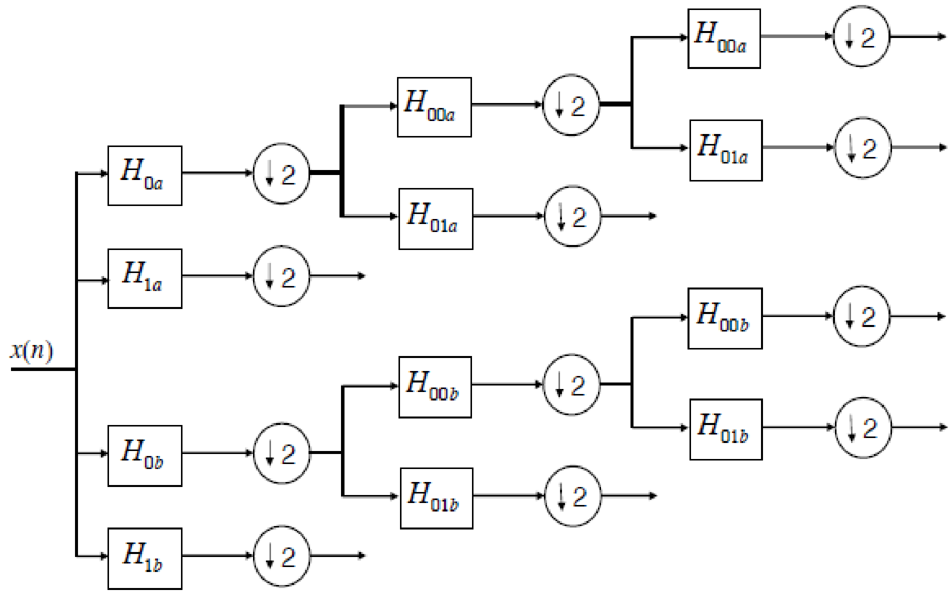

Fig. 2: 1D Dual Tree Complex Wavelet Transform

4.3 The Wavelet Packet Transform

DTXWT is an over complete wavelet that provides both good shift invariance and directional selectivity over the discrete wavelet transform (DWT) and is computationally faster than the Gabor transform. The transform is suitable for signals consisting primarily of smooth components so that their information is concentrated in the low frequency regions. However, it may not be suitable for quasi-periodic signals such as speech signals and texture signals whose dominant frequency channels are located in the middle frequency region.

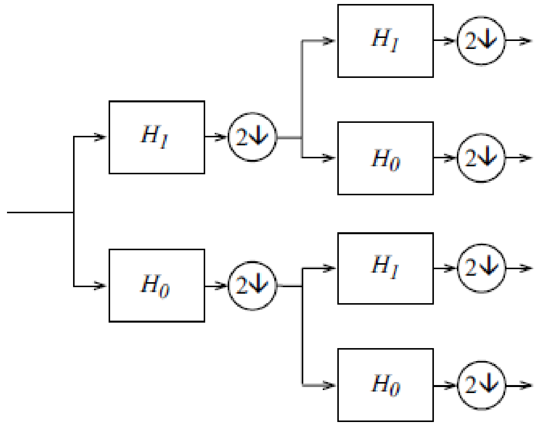

Fig 3: Full 1D wavelet packet binary tree for two levels

Thus, an appropriate way to perform the wavelet transform for textures is to detect the significant frequency channels and then to decompose them further. The above idea leads naturally to a new type of wavelet transform called the tree-structured wavelet transform or the discrete wavelet packet transform (DWPT) as shown in Fig 3. To selectively decompose the subbands we may consider a criterion like Energy, Variance, Entropy etc to decide whether a decomposition is needed for a particular output. Best-basis selection algorithm helps in identifying the suitable subbands [18].

4.4 The Dual Tree Complex Wavelet Packet Transform

However, like the DWT, the DWPT is also shift-variant and mixes perpendicular orientations in multiple dimensions causing artifacts.

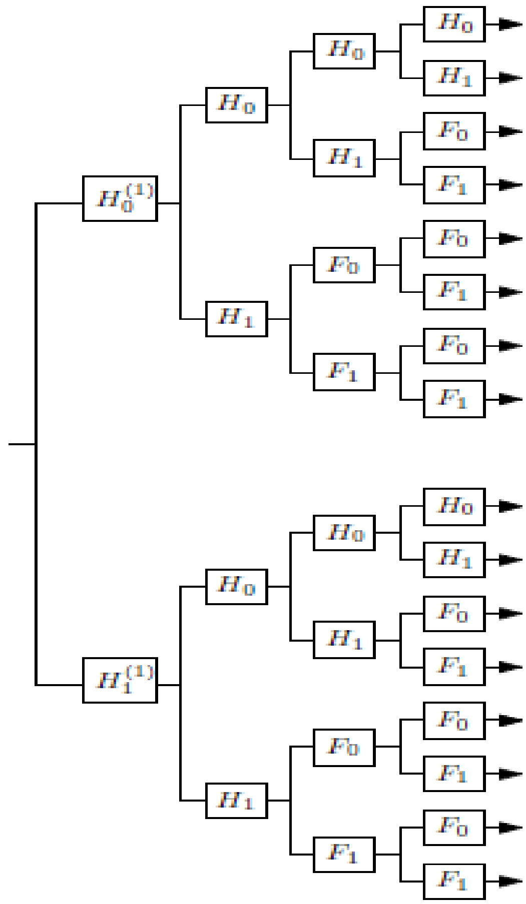

Fig 4 : One tree of a dual tree complex wavelet packet transform with four stages

It is not rotation invariant because of its separability. To exploit the advantages of the complex transform and the packet transform, the combined transform or the dual tree complex wavelet packet transform (DTXWPT) has been chosen in our work for further experiments (Fig 4).

4.5 Texture Gradient

In this work we attempt the morphological method of segmentation using the Watershed Transformation technique. It uses a type of region growing method based on an image gradient. The relatively new concept of **texture gradient** introduced by Hill et al [19,20] has been used in our work for formation of the gradient image.

This consists of a number of conceptual stages as outlined below:

1) Compute a texture representation that characterizes a local area surrounding each pixel.

2) Post process the texture features to make them suitable for meaningful gradient extraction

3) Generate gradient images for each of the texture features as well as for grayscale intensity

4) Normalize/weight the contribution of each gradient image

5) Combine the various gradient images to form the single valued gradient surface.

4.6 Marker image creation

The watershed technique [21,22] is a region-growing algorithm that analyzes an image as a topographic surface. It detects the regional minima of the gradients in the gray level image and grows these minima according to the gradient values. It can be viewed as a flooding process. The best-known drawback of the watershed transform is the tendency to over segment. The solution often proposed is to use a marker-based watershed transposing the problem to that of marker selection.

The aim of marker identification is to identify regions that are homogeneous in terms of texture, color and intensity and of a significant size. To meet these criteria a minimum region size, moving threshold and region growing method was adopted . This algorithm calculates the median and standard deviation of the gradient image (TG). Then several thresholded binary images are produced at reasonably spaced thresholds using the median and standard deviation of TG. For each binary thresholded image, the number of closed and connected regions greater than the given minimum size is calculated. The threshold with the maximum number of connected regions is used for the output marker image.

4.7 The Watershed Transform segmentation

Many sequential algorithms have been developed to compute watershed transforms. The watershed algorithms can be divided into two groups. The first group contains algorithms which simulate the flooding process. The second group aims at the direct detection of watershed points. The marker-based watershed approach follows the principles of immersion simulations but imposes some markers (either determined through user interactions, or extracted automatically) as minima and suppresses other unwanted minima to overcome the over-segmentation problem. Regional minima in a given image are detected through the markers, and unique labels are given to the minima first. Starting from minima ordered region growing is performed.

To implement the watershed algorithm, we have adopted a strategy of using appropriate arrays to store the labels and a repeated sequential scan based method for labeling. We adopt a technique similar to parallel and pipeline processing. Each component (pixel) in the image is connected to its lowest neighbor component, and all components which leads to the same lowest component (local minima) forms a segment.

5. Experimental results

The Brodatz image database with 116 images that have significant amount of texture information were chosen for performance evaluations. Every original image is of size 512 x 512 pixels with 256 gray levels. All textures are gray-scale images when presented to the methods. The dynamic ranges are represented by eight bits per sample. For medical images we have used a set of images obtained from Sree Chitra Institute of Medical Sciences consisting of MRI images of the brain, Ultra sound images of the kidney, cell image, lung image etc.

In our initial experiments, a simple set of texture classification experiments was conducted to test the developed methods and metrics. Many ways are reported for characterizing texture from the sub bands like energy measures, mean, variance, entropy etc. For example, energy features from each sub band can be calculated using the l_1 norm. Each energy measure characterizes the magnitude of frequency content at the orientation and scale of each sub band.

A minimum distance classifier is used utilising the mean feature vector and covariance of the test and training images to classify each test texture image. In particular, we consider four such functions namely the Euclidean distance, the Bayes distance, the Mahalanobis distance and the simplified Mahalanobis distance. Experiments were conducted with the XWT as well as the DTXWPT. The classification results show increase in overall classification rate to the extent of 80 to 90 % for the DTXWPT when compared to the other two signifying better feature characterization.

In the succeeding experiments with DTXWPT, we used both texture images and medical images for our test cases. Excellent segmentation results were obtained for texture images as well as medical images with the Texture Gradient Watershed method. A minimum region size for local minima controlled by *minsize* parameter determines the number of local minima regions for marker image. By suitably choice of the minimum region size, over segmentation is controlled to a large extent.

An exhaustive study of comparable segmentation results is unfeasible. For results sake, we implemented two additional methods of segmentation. The first scheme incorporates the statistical method of feature extraction using Gray Level Co-occurrence Matrix (GLCM), an initial clustering with the Expectation Maximisation (EM) algorithm followed by using the Bayesian classification algorithm for further classification. A second alternative we tried in our experiments involves use of Gabor filters for feature extraction followed by generation of a feature map through Self Organising Map (SOM) and applying the Canny operator for edge detection from the feature map.

Segmentation performance evaluation remains subjective to a large extent. Supervised evaluations are used to find the quality of segmentation. We follow the GT-based evaluation paradigm. The Corel database provides the necessary ground truth images for reference. The widely used metrics of Local Consistency Error (LCE) and Global Consistency Error (GCE) is used in our experiments for evaluating the segmentations. The small values of GCE and LCE

obtained with the Texture Gradient Watershed method clearly indicate the superior performance of the proposed method over the comparison methods.

6. Conclusion

The thesis has been devoted to study the problem of image segmentation and to propose algorithms to solve it. Morphological methods along with Texture Gradient was chosen to introduce new efficient segmentation methods for images with textures. The main reason is that this model offer a rigorous mathematical framework. The results show that the segmentation implemented through Texture Gradient Watershed method is superior to the others methods and it performs equally well with respect to manual segmentation.

The main contributions are summarized as follows:

- Implemented a novel computationally efficient texture characterizing methodology using the Dual Tree Complex Wavelet Packet Transform (DTXWPT).

- Developed an economical, accurate smoothing methodology for fusing the selected complex subbands using a seperable, oriented weighted median filter

- Used the concept of texture gradient to generate gradient images permitting segmentation of texture images as well as natural images according to their texture content together with intensity content.

- Developed a novel marker image creation method to pinpoint regions that are homogeneous in terms of texture, intensity and of a significant size. To meet these criteria a minimum region, moving threshold and region growing method was adopted

- Developed a novel flooding algorithm based on sequential repeated scan and arrays to implement the watershed algorithm

The main limitations observed are summarized as follows:

- Even though it is stated that the filter selection does not have much influence on the texture classification, we observe that choice of a filter bank in the wavelet texture characterization could be an important issue, possibly affecting the quality of the description. This is clear from our initial experiments with the discrete wavelet transform followed by the successive expansive transforms. A filter with good frequency localization is essential for good segmentation results. Therefore choice of appropriate filters plays a big role in the final outcome.

- For texture images in which the repetition of patterns are infrequent, we find that intensity gradient dominates texture gradient and hence the final texture gradient images do not give satisfactory results in spite of the ideal post processing methods applied.

- The choice of the minimum region size of the local minima decides the final number of segmented regions. Random values will cause over segmentation. Hence the *min size* parameter value has to be chosen with care.

7. Future work

During this thesis work, many areas were investigated to examine the feasibility of incorporation in a segmentation framework. There are still so many others areas to explore for improving the texture characterization like use of graph methods, fractal methods etc or a combination of these.

The selection of subbands for wavelet packet splitting can be explored with graph cut methods for better and adaptive texture gradient.

The texture gradient was based purely on the basis of the wavelet coefficient magnitudes and its discontinuity. Phase discontinuities are also important for identifying texture boundaries. Therefore a combination of measures could be investigated for better texture gradient.

The marker image determines the quality of the final segmentation to a large extent. As stated earlier, the *minsize* parameter in the marker image creation algorithm is the key parameter for successful segmentation of natural images. Automatic generation of the minimum region size tuned to the information content of the image will help in better segmentation. Moreover an intelligent evaluation of the marker regions created will provide a better marker image.

Post processing through methods such as selective region merging will enhance the quality of the segmented results.

There are a number of important possible further developments to the above marker selection and texture gradient methods.

Key References

[1] M. Unser, "Texture classification and segmentation using wavelet frames," IEEE trans. on Image Processing, vol. 4, no. 11, pp.1549– 1560, 1995.

[2] B.Wang and L. Zhang, "Supervised texture segmentation using wavelet transform," Proc. of the 2003 International Conference on Neural Networks and Signal Processing, 2003, vol. 2,pp. 1078-1082.

[3] Chang- Tsun Li and Roland Wilson, "Unsupervised texture segmentation using multiresolution hybrid genetic algorithm," in Proc. IEEE International Conference on Image Processing ICIP03 ,2003, pp. 1033– 1036.

[4] T.R. Reed and J. M. H. Du Buf, "A review of recent texture segmentation, feature extraction techniques," in CVGIP Image Understanding , 1993, pp. 359– 372.

[5] A.K. Jain and K. Karu, "Learning texture discrimination masks," IEEE trans. of Pattern Analysis and Machine Intelligence, vol.18, no. 2, pp. 195-205, 1996.