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Approach for Super Resolution in Ultrasound Imaging: An Overview

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***Abstract*— Ultrasound imaging is a wide spread technique used to view body soft tissues, like tendons, muscle or internal organs for possible problems. These images are achieved by capturing the returned acoustic waves using an ultrasonic transducer. Due to the propagation in imperfect environment, the resolution of these images has a poor quality. The requirements for better resolution currently represent a very important and open challenge. Accurate measurement and visualization of structure in living tissues is intrinsically limited by the imaging system features. Imaging beyond these limits in medical imaging is referred to as super-resolution. This paper intends to provide a brief overview of super-resolution imaging and to achieve a preliminary synthesis of the most important directions of study for the resolution improvement.**

Keywords— Image super-resolution, Spatial Resolution, ultrasound, medical image, digital image processing

I. Introduction

In almost every application (Medical Imaging, high definition televisions-HDTV or web-based images), it is desirable to generate an image of good quality. The quality of image suffers from low resolution, noise and imaging artifacts. High resolution image plays a vital role in the area of medical imaging applications. The purpose of medical imaging is to create visual representations of the interior of a body for clinical analysis and display of the function of some internal organs or tissues (physiology). Medical imaging is required to reveal hidden internal structures under skin and bones, as well as to diagnose and treat disease [1].

The main goal of medical imaging is to extract a 3-D modeling of the human body or specific organs within it hence the need for high resolution is common in medical imaging for better performance and analysis of images. The higher resolution (HR) images contain the accurate spatial and intensity information and hence help us to provide more accurate understanding of the anatomy, to support early detection of abnormalities and to increase the accuracy in the estimation of size and morphology of organs and pathologies for more accurate localization of a tumor or accurate diagnosis of the diseases.

The resolution of an image is dependent on the resolution of the image acquisition devices. Finer spatial sampling may be obtained through a longer acquisition time but that would also increase the probability of patient movement and thus blurring so there must be a deliberate trade-off between acquisition time and cost. However, high resolution images are not always available. The installation of setup for high resolution imaging system proves expensive and also it may not always be feasible due to the limitations of the sensor and optics manufacturing technology. As the resolution of the image generated by a device increases, so does the cost of the device. Any imaging systems have an upper limit on resolution.

The demand for high-resolution (HR) images can be met by advancement of algorithms related with image processing rather than hardware advancement which is costly and complex. Therefore a super-resolution (resolution enhancement) approach using computational, mathematical, and statistical techniques has received a great attention recently. It provides an advantage as it offers less cost and the existing low resolution imaging systems can also be utilized.

Need of Ultrasound images: Ultrasound imaging is helpful in many types of examinations and procedures. Some examples include:

- Doppler ultrasound used to visualize blood flow through a blood vessel
- Bone sonography used to diagnose osteoporosis
- Echocardiogram used to view the heart
- Fetal ultrasound used to view the fetus in pregnancy
- Ultrasound-guided biopsies
- Doppler fetal heart rate monitors used to listen to the fetal heart beat

***Ultrasound imaging* [2]:** The idea of ultrasound differs from other medical imaging modalities in the view that it is operated by the transmission of sound wave and reception of their echo. Transducer produces the Ultrasound waves which pass through body tissues and when the wave incidents on an object or surface with different texture or acoustic nature, it is

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reflected back. Medical ultrasonography uses broadband high frequency sound waves in the megahertz range (in 3 to 20 MHz range) that are reflected by tissue and depending on the composition of the different tissues; the signal will be attenuated and returned at separate intervals to produce images [3].The reflected waves (echoes) are received by the apparatus (the transducer array) and converted into electric current. These signals are amplified and shown on a display device in real time. The image generated using Ultrasound imaging (Ultrasound Scanning) is known as Ultrasonogram. At the time of image acquisition process, there could be distortions, which will give noisy images. The diagnosis based on these images will not appropriate. This emphasize the usefulness of advanced digital image processing techniques for improving the quality by removing noisy parts present in the acquired image to have a better diagnosis. The occurrence of noise parts is more on Ultrasound image compared to other costlier methods like CT and MRI. In this paper, I present a survey based on different techniques used in ultrasound image denoising.

Different modes of ultrasound imaging are used for examination in medical or industrial use. A mode is an operational state that a system has been switched to. The three different modes of ultrasound imaging are [3] (i) b-mode (Brightness Mode) – It is basic two-dimensional intensity mode, which involves propagating small pulses of ultrasound echo from a transducer into the body. B-Mode is based on brightness which depends upon the amplitude or intensity of the echo. B-Mode will display an image in large and small dots, which represents strong and weak echoes respectively. (ii) m-mode (Motion Mode) - It is also called Time Motion or TM-Mode and used to assess shimmy body parts (e.g. cardiac movements) from the echoed sound. This is used for analyzing moving body parts commonly in cardiac and fontal cardiac imaging. This can be done by recording the amplitude and rate of motion in by iteratively measuring the distance of the object from the single transducer at a particular moment. The single sound beam is emitted and the reflected echoes are displayed as dotes of varying intensities thus creating lines across the screen. (iii) Doppler mode (Color mode) - Doppler Mode uses the idea of frequency shift due to relative motion between two objects. With this approach information regarding fluid velocity can be obtained. Continuous or pulsed wave are used to get the Doppler mode.

Steps of Ultrasound signal acquisition Process: For setting up the background for discussing the possibilities of noise in Ultrasound image, a brief introduction of the Ultrasound imaging process is given below.

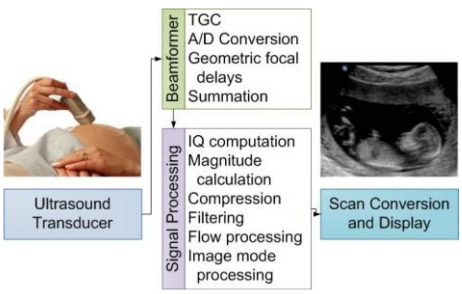

Figure 1: Steps of Ultrasound Imaging System

Step-1: Bring the Object under transducer for the examination or investigation. The transducer is responsible for the conversion of electrical signals to mechanical energy and the conversion of returned mechanical energy back into electrical energy. The resulting signal or image quality depends on the characteristics of the transducers such as central frequency and bandwidth.

Step-2: Beamformer (Transmiter/Receiver) component controls the US signal emission, beam-forming, reception, and conditioning. It is a front end processing. Directions of the transducers are aligned for focusing the ultrasound waves at different focal lengths along a given scan-line. The transducers are switched on and then off. During the off time, they listens the wave echoed by the body cells. The intensity at a given focus point is computed as the sum of the sound waves received by all the neighboring transducers listening just after sending the waves focused at that point.

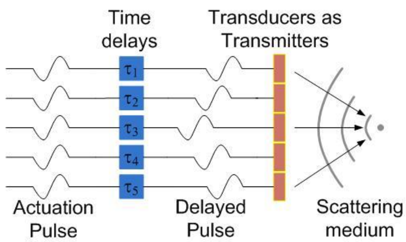

Figure 2: Ultrasound Imaging – Wave Transmission

Step-3: To form the best quality ultrasound images, it is often necessary to perform some operations before displaying the information for observation. The summed signal is then passed to the Signal processing block, where the signal envelope is extracted, decimated and then log compressed to fit the dynamic range to that required by the system to generate the image. Different axial and lateral filters are applied on the signals at different stage to improve the image quality. The processing and their order depend on the overall system configuration.

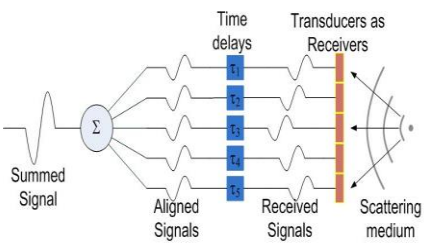

Figure 3: Ultrasound Imaging – Wave Listening

Step-4: The processed signal will then be given to the Scan conversion module as scan lines, which then actually generate the image from the scan lines by doing a geometric mapping as shown in Figure 4. The final image is generated by interpolating the image pixels from the mapped scan lines. The device/monitor shows the output/result of the entire US image acquisition system. The output of the signal processing must be in such a form that is compatible with the type of display used.

Noise can be introduced at all steps of Image acquisition. One of the reasons of noise is due to the improper contact or air gap between the Transducer probe and body. The noise could be introduced during the beam forming process and also during the signal processing step. Even during the Scan conversion, there could be loss of information due to the interpolation.

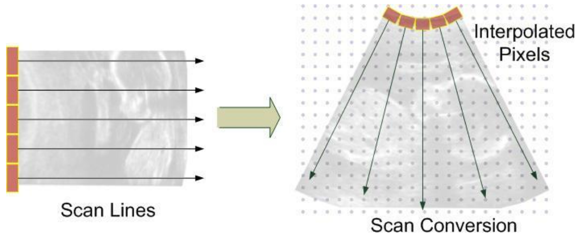

Figure 4: Ultrasound Imaging – Scan Conversion

Image quality enhancement during acquisition: Ultrasound image quality can be improved during the acquisition by (a) using high quality transducers, (b) using gel to ensure proper contact and to avoid air gaps between body and the probe, (c) Using appropriate axial and lateral filters while doing the signal processing and (d) by using adaptive interpolation techniques while doing the scan conversion. We are not discussing these techniques in detail since the focus of this survey is the application of Digital Image processing techniques in improving the quality of the acquired image.

Advantages of Ultrasound Images: There are many advantages which make it suitable in various situations [4],

- To study the function of moving structures in real-time
- It emits no ionizing radiation, and contains speckle that can be used in elastography.
- It is very safe to use and without any adverse effects.
- It is inexpensive and ready to perform.
- Excellent for fluid filled cavities (cyst), liver, foreign bodies, and obstetric imaging
- Ultrasound scanners are handy and can be taken to critically ill patients in intensive care units, avoiding the danger caused while taking the patient to the radiology department.
- To get the real time image that can be used to guide drainage and biopsy procedures.
- Doppler capabilities enabled scanners allow the blood flow in arteries and veins to be assessed.
- Ultrasound is used as a research tool for capturing raw data for the purpose of tissue characterization.

II. IMAGING PROBLEM

The degree of spatial resolution depends on the profiles of the ultrasonic beam and pulse as well as the characteristics of the signal processing and display system. A transducer array can be used either as a simple aperture, in which all the elements are active till the signal acquisition process completes, or the aperture size can be adjusted to maximize the spatial resolution throughout the depth of penetration. In developing an imaging system, a true criterion is to maintain a constant ratio between focal length and diameter (*f* –number), independent of the axial position of the object. This can be achieved by expanding the effective size of the aperture by increasing the number of active elements in the transducer array with time following the transmission of the pulse, to maintain the receiving beam width at the focus stay constant. There are many other advantages also with this approach. There is a limit in maximum aperture size and beyond which there is no further improvement in spatial resolution possible. Imaging modalities are badly affected by the low resolution environment for e.g. X-rays offer low contrast for soft tissues, metallic implants will cause imaging artifacts in MR and ultrasound produces noisy images. Finer spatial sampling is the result of long acquisition time. However that would also increase the probability of patient movement and thus blurring.

The resolution of the ultrasound image can be enhanced by using higher frequency range but at the same time it limits the depth of the penetration. In this paper, we do a survey of different Digital Image Processing techniques used in enhancing the information quality in the Ultrasound image.

***Challenges in Super Resolution* [5]:** Image resolution is defined as the smallest quantifiable detail in a visual presentation. It means that pixel density is high within an HR image and therefore offers more details that may be significant in various applications. In super-resolution (SR) imaging we obtain a high resolution image from a set of low resolution observations. High pixel density in a high resolution image ensures more details about the original scene. High resolution medical images are important in medical imaging for diagnosis purpose.

In super resolution (SR) approach we use several low-resolution (LR) images from a particular imaging system to estimate and reconstruct the high-resolution (HR) source. Each LR input image focuses on a slightly shifted field-of-view or point-of-view of the HR scene. There are different reconstruction algorithms have been proposed, with the aim to estimate the HR source as accurately as possible as well as minimizing noise and preserving important image constraints, which includes image smoothness and additional prior knowledge about the source. The aim is then to recover the high resolution image which when resample based on the input images and the imaging model that will produce the low resolution observed images. Thus the accuracy of imaging model is essential for super-resolution and an erroneous modeling, say of motion, can actually degrade the image further. The observed images could be taken from one or more cameras or could be frames of a video sequence. These images are required to be mapped to a common reference frame. This process is known as registration. The super-resolution procedure can then be implemented to a region of interest in the aligned composite image. The key to successful super-resolution consists of precise alignment i.e. registration and formulation of an appropriate forward image model [6].

The imaging system presents number of unusual and challenging situations some of which are unique to ultrasound image acquisition scenario [7].

i) **Image registration:** The multiple low resolution images can represent different view-points of the same scene. In image registration process we map corresponding points in these images to the actual points in original scene and transforming data into one coordinate system. Different types of transformations are required for registration of images like biquadratic transformations, affine transformations. When the LR images are aligned geometrically, there may be considerable photometric variation, because of different levels of lighting as well as camera exposure settings when the images were captured. Small image displacements are crucial for overcoming the sampling limit of the original acquisition device, but the exact mappings between these images are still unknown. To achieve an accurate super-resolution result, they need to be found as precisely as possible.

ii) **Forward Imaging Model:** One of the most important aspects in super-resolution is good formulation of a model for the motion and imaging process. A forward model correlates the original scene to the observed low resolution images.

iii) **Blur identification:** Due to patient movement blurs introduced in the image. The blurs introduced is modeled by a point-spread function (PSF).

III. BRIEF LITERATURE SURVEY

Super Resolution: The main goal of super-Resolution (SR) is to get a higher resolution image from available lower resolution images. The concept of Super-resolution is based on the idea that a set of low resolution (noisy) sequence of images of a scene are used to create a high resolution image or image sequence. Thus SR attempts to reconstruct the high resolution original scene image with given a combination of observed images at lower resolution.

Any of the super-resolution image reconstruction methods consist of three basic mechanisms: (i) motion compensation (ii) interpolation and (iii) blur and noise removal. Mapping of motion from all available low resolution frames to a common reference frame is motion compensation. The motion field can be modeled in terms of motion vectors or as affine transformations. The second mechanism refers to mapping the motion-compensated pixels onto a super-resolution grid. The third mechanism is needed to remove the sensor and optical blurring. Several SR reconstruction methodologies have been developed in the last few years. Some of the existing basic image super-resolution schemes are:

SR by Sparse Representation [8]:
The image patches can be represented as a sparse linear combination of elements from an properly chosen over-complete dictionary. Based on this fact Jianchao Yang *et al*. considered the sparse signal representation of an image and proposed a sparse representation for each patch within the low-resolution image. The coefficients of this representation are used to generate the high-resolution image. Theoretical results suggest that the sparse representation can be correctly recovered from the down-sampled signals under mild conditions. Match of sparse representations between the low-resolution and high-resolution image patch pair in relation with their own dictionaries is imposed, by jointly training two dictionaries for the low and high-resolution image patches. Hence, the sparse representation of a low-resolution image patch is used with the high-resolution image patch dictionary to get a high-resolution image patch. This algorithm can handle SR with noisy inputs in a more unified framework because the local sparse modeling is naturally robust to noise.

Nonlinear Mapping of Coherent Features [9]**:**
A regression based method that can successfully recognize the identity given all these difficulties proposed by Xiao Zeng and Hua Huang. They deviced a radial basis function in subspace with the help of canonical correlation analysis from the specific non frontal low resolution image to frontal high resolution image.

Geometric Grouplets [10]**:**

The idea of generating a super-resolution (SR) image from a single multi-valued low-resolution (LR) input image is proposed by A. Maalouf and M. C. Larabi. This problem approaches from the perspective of image geometry-oriented interpolation. They computed grouplet transform to obtain geometry of the LR image. Geometric grouplets is formed by orthogonal multi-scale grouping with weighted Haar lifting to points grouped by association fields. They synthesized SR image to preserve the sharpness of edges and textures by an adaptive directional interpolation using the extracted geometric information. This method showed improvements over existing geometrically driven interpolation techniques on a subjective scale, and also shows an improvement in psychovisual color difference.

Remotely Sensed image by Hopefield Neural Network [11]**:**
J Tatem Andrew *et al*. applied the concept of super-resolution in the application area of target identification in remotely sensed images. Fuzzy classification improves the accuracy of land cover target identification make robust and better for spatial representation of land cover. The Hopfield neural network converges to a minimum of an energy function, defined as a goal and several constraints. The energy minimum represents a best guess map of the spatial distribution of class components in each pixel. To make the output of a neuron similar to that of its neighboring neurons, they used two goal functions. The purpose of first goal function is to increase the output of center neuron to 1 and the purpose of the second goal function is to decrease the output of the center neuron to 0. They observed that, by implementing a Hopfield neural network, more accurate measures of land cover targets can be obtained compared with those computed using the proportion images alone. By the results, the Hopfield neural network used in this way represents a simple, robust, and efficient method, and suggests that it is a useful tool for identifying land cover targets from remotely sensed imagery at the subpixel scale.

Neural Network based Optimal Recovery Theory [12]
Yizhen Huang and Yangjing Long proposed a optimal recovery based neural-network Super Resolution algorithm. This method evaluated on classical SR test images with both generic and specialized training sets, and compared with other state-of-the-art methods. Motivated by the idea that back propagation neural network are capable of learning complex nonlinear function they proposed a neural network approach that produces better results in high-frequency regions. They integrated an optimal recovery based approach with in a neural network framework and, if so, two different branches of algorithms complement each other to offer a better algorithm. Using this algorithm in a two-pass way generates visual results that are very similar regardless of the initial interpolation step, and more times of iteration only waste the computing resource but yield negligible performance gain.

Gaussion Process Regression [13]
He and Wan-Chi Siu addressed the problem of producing a high-resolution image from a single low-resolution image without any external training set. They proposed a framework for both magnification and deblurring using only the original low-resolution image and its blurred version. In This method, each pixel is predicted by its neighbors through the Gaussian process regression. They showed that, by using a proper covariance function, the Gaussian process regression can perform soft clustering of pixels based on their local structures. This algorithm can extract adequate information contained in a single low-resolution image to generate a high-resolution image with sharp edges. Compared to other edge-directed and example-based super-resolution algorithms this algorithm is superior in quality and performance.

Learning-based SR with a combining of both global and local constraints [14]
A statistical learning method for super resolution with both global and local constraints is proposed by K. Guo *et al*. They introduced a fusion model into maximum a posteriori (MAP) estimation. In this approach combine a global parametric constraint with a patch-based local non-parametric constraint. The global parametric constraint guarantees the super-resolved global image to agree with the sparse property of natural images, and the local non-parametric constraint is used to infer the residues between the image derived from the global constraint and the ground truth high-resolution (HR) image. They compared it with traditional patch-based learning methods without the global constraint, and showed that this method restore the local details more effectively as well as preserve global image structure.

Interpolation based SR using Multisurface Fitting [15]
Fei Zhou *et al*. used the idea of multisurface fitting to take advantage of spatial structure information and devised an interpolation-based method of image super-resolution reconstruction. Each site of low-resolution pixels is fitted with one surface, and the final estimation is made by combining the multisampling values on these surfaces against posteriori fashion.

Interpolation based SR using Wavelet Domain High Frequency Subbands [16]
A super-resolution technique is proposed by Gholamreza Anbarjafari and Hasan Demirel based on interpolation of the high-frequency subband images obtained by discrete wavelet transform (DWT) and the input image. They used DWT to decompose an image into different subband images. These obtained high-frequency subband images as well as the input low-resolution image have been interpolated and then mixing all these images to get a new super-resolved image by using inverse DWT.

Complex Wavelet Transform based Super Resolution [17]

Gholamreza Anbarjafari and Hasan Demirel used DT-CWT (Dual-Tree Complex Wavelet Transform) to decompose an input low-resolution satellite image into different subband images and interpolate input images followed by combining all these images to get high-resolution images by using inverse DT-CWT. To enhance the resolution of satellite images they used this technique based on interpolation of high-frequency subband images obtained by (DT-CWT).

Discrete and Stationary Wavelet Decomposition based IMAGE Resolution Enhancement [18]
Interpolation of the high frequency subband images based image resolution enhancement technique which is obtained by discrete wavelet transform (DWT) and the input image is proposed by Gholamreza Anbarjafari and Hasan Demirel. For enhancing the edges they introduced an intermediate stage by using stationary wavelet transform (SWT). The purpose of the DWT is to decompose an input image into different subbands and after that the high frequency subbands as well as the input image are interpolated. The estimated high frequency subbands are being adapted by using high frequency subband obtained through SWT. Then all these subbands are combined to get a high resolution image by using inverse DWT (IDWT).

IV. CONCLUSION

The requirements for better resolution in all medical imaging modalities currently represent a very important and open challenge. Accurate measurement and visualization of structure in living tissues is intrinsically limited by the imaging system features. In the first contribution qualitative analysis has been made. This suggested implementation of SR based nonlinear ND method for noise reduction as well as to preserve and enhance edge and structure details in future. To test the proposed method, in the future, we would like to do experiments in ultrasound images. In addition, registration in the SR method is very important, inaccurate registration will result in a poor image restoration. So, improving the registration method in the SR method is another future work.
class description. The nature of the environment is dynamic hence the model must be adaptive i.e. should be able learn.

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