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Design of 2D ultrasound Scanner Using Compressed Sensing and Synthetic Aperture (CS-SA) technique

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Abstract– **Recent developments in medical treatment put challenging demands on ultrasound imaging systems. These demands typically imply increasing the number of transducer elements involved in each imaging cycle. Confined to traditional sampling methods, the inevitable result is a significant growth in the amount of raw data that needs to be transmitted from the system front end, and then processed by the processing unit, effecting machinery size and power consumption. One of the major downside of these systems is that the cost of system is high. The main focus of project is to make the ultrasound system more affordable. The cost of system is proportional to the number of sensor used in the system. Reducing the number of sensors and applying the existing algorithm will reduce the resolution of ultrasound images obtained from the system.**

Compressed Sensing (CS) has emerged as a new framework for signal acquisition and sensor design. CS enables a potentially large reduction in the sampling and computation costs for sensing signals that have a sparse or compressible representation. In synthetic transmit aperture medical ultrasound imaging field, a compressed sensing ultrasound imaging method based on the sparsity in frequency domain is presented in order to reduce huge amount of data and large numbers of receiving channels. First, the sparsity in frequency domain is verified. Then the echo signal is compressively sampled in time-spatial domain based on compressed sensing and the echo signal is reconstructed by solving an optimization problem. Finally the image is made by using the synthetic transmit aperture approach. The amount of data and the complexity of system are reduced greatly by the proposed method based on compressed sensing. In this paper we compare the Phased array imaging and Synthetic Transmit Aperture(STA) imaging without applying a compressed sensing. As compare from the results above acquisition time for STA is reduced to 1/3 of phase array imaging.

Keywords:Compressed Sensing, Synthetic Aperture , sparsity, sampling, resolution

I. INTRODUCTION

In ultrasound-based diagnostic imaging, ultrasonic pulses are transmitted into the scanned tissue. Reflections of the transmitted energy, caused by density and propagation-velocity perturbations in the tissue [1] , are then measured by an array of transducer elements. Applying the acoustic reciprocity theorem, data from multiple elements is digitally integrated in the processing unit, in a process known as beamforming [2] , which results in significant SNR enhancement.Digital beamforming requires sampling the signals detected in all active elements, and then transmitting the samples to the processing unit. Confined to the classic Nyquist-Shannon theorem[3] , traditional methods require that this data be sampled at twice the baseband bandwidth of the detected signals. Avoiding artifacts, caused by the digital implementation, requires that the data be sampled at even higher rates, typically 3-5 times the center frequency of the transmitted pulse. Sampling at such rates is not necessarily a bottleneck in modern systems. On the other hand, as imaging techniques evolve, the number of elements involved in each imaging cycle grows significantly. Consequently, large amounts of data must be transmitted to the processing unit, posing an engineering challenge. This motivates compression of the sampled data, before its transmission to the processing unit. In ultrasound (US) imaging, the amount of data can be a limiting factor for real-time imaging or simply data storage. Compressive sampling (CS) or compressed sensing is a novel theory aiming to reduce the amount of data collected during the acquisition that emerged in 2006 [4]. The principle of CS is to measure only a few significant coefficients of a compressible signal and then to reconstruct it through optimisation. It differs from compression as the signal is directly acquired (or sampled) in its compressed form.

Various schemes have been suggested to reduce the data volume in ultrasound systems. In [5], the authors compressed the raw RF ultrasound data and/or the baseband data using JPEG and JPEG2000 techniques. This requires Nyquist sampling as the first stage. In [6], the authors demonstrated the feasibility of Compressive Sensing (CS) for the reconstruction of an ultrasound RF signal. However, interpolation filters and/or phase rotation units are required in the mid-end. In [7], the authors proposed a sub-Nyquist sampling architecture by exploiting the finite rate innovation of the ultrasound signal. This system achieves 8-fold data reduction at the expense of a collection of dedicated preconditioning filters for each transducer element.

The purpose of the paper is to design a ultrasound transducer with minimum number of element(≤ 64 element).We derived a method derived method to reconstruct radio-frequency(RF) US image from a spatial samples. First the theory of compressed sensing is briefly reviewed. Then synthetic aperture transmitter aperture along with CS is explained. Finally the reconstruction of US image is explained then the result is discussed.

II. THEORY OF COMPRESSED SENSING

The principle of CS is to sample and recover sparse signals from fewer samples than requested by the Shannon sampling theorem. Signals sparse in a given domain contain only a few significant coefficients in this basis. By compression, i.e.setting the non-significant coefficients to zero, it is possible to recover almost exactly the original signal. For images, well known cases include compression by discrete cosine transform (JPEG format), wavelets (JPEG 2000), etc. Ideally, when acquiring compressible data, only the most significant coefficients would be measured and from those few samples, the signal would be recovered. There is a problem for acquire those few samples without any prior knowledge on the signal.

CS gives an answer to this problem by sampling the signal in a completely incoherent way, the most intuitive sampling strategy being random linear combinations of the signal. Each measurement contains information about the whole signal but the number of measurements is low compared to the Nyquist sampling criteria [4].

The reconstruction of the signal from those few measurements, which is an inverse problem, is then performed through an optimization process. It has been shown that, if the number of measurements is sufficient, amongst all the signals that match those samples, the one with the fewest coefficients in the sparse domain will be the original signal [8]. Mathematically, the idea of CS translates as follows.

Consider the signal to recover, for example, an image m in R^N,sparse in a basis Ψ of $R^{N\times N}$ so that s=Ψm has S non-zero entries (with S << N). Assume m is sampled using a sampling basis A in $R^{K\times N}$, incoherent with the sparsifying basis Ψ, resulting in measurements y=Am, with y in R^K.

The original image can be reconstructed resolving the constrained optimization problem:

$$\min \left| \Psi m \right| \text{ s.t. } A m = y \qquad (1)$$

where $|\,|$ denotes a l1 norm. Equation (1) states that,among all the solutions that verify the measurements, the original image m is the one with minimum l1 norm in the sparsifying basis, i.e. the sparsest in Ψ [5].

The success of that reconstruction is guaranteed with overwhelming probability if:

- $K \geq C\cdot\mu^2(A,\Psi)\cdot S\cdot\log(N)$, where C is a constant and μ(A,Ψ) is the coherence between the sampling and sparsifying bases [6]:
$$\mu(A,\Psi) = \sqrt{n}\max_{1\leq k,j\leq n}\left|\langle A_k, \Psi_j\rangle\right| \qquad (2)$$
where < > is the inner product (correlation).
- the signal m is **sparse** in a basis Ψ,
- the sampling basis A and sparsifying basis Ψ are **incoherent**.

III. THEORY OF SYNTHETIC APERTURE TECHNIQUE

A. INTRODUCTION

As consider for conventional ultrasound imaging system, when one transducer or linear array are used, the quality of images directly depends on the transducer acoustic field. Also in conventional ultrasound imaging the image is acquired sequentially one image line at a time that puts a strict limit on the frame rate that is important in real-time imaging system. Low frame rate means that moving structures are not easily imaged and diagnosis may be impaired. This limitation can be reduced by employing synthetic aperture (SA) imaging. The basic idea of the SA method is to combine information from emissions close to each other. The synthetic aperture method now a day's play a important role in medical imaging. This is shown in Fig.1. This method is a contrast to the conventional beamforming, where only imaging along one line in receiving is used. This means that every image line is visualized as many times as the number of elements used. This will create an equal amount of low resolution images, which are summed up to create one high resolution image.

B. VARIOUS METHODS OF SYNTHETIC APERTURE TECHNIQUE

The idea of synthetic aperture has been used in ultrasound imaging systems. In this case, the benefit of the synthetic aperture has been the reduction of system complexity and cost. Several methods were proposed to form a synthetic aperture for ultrasonic imaging.

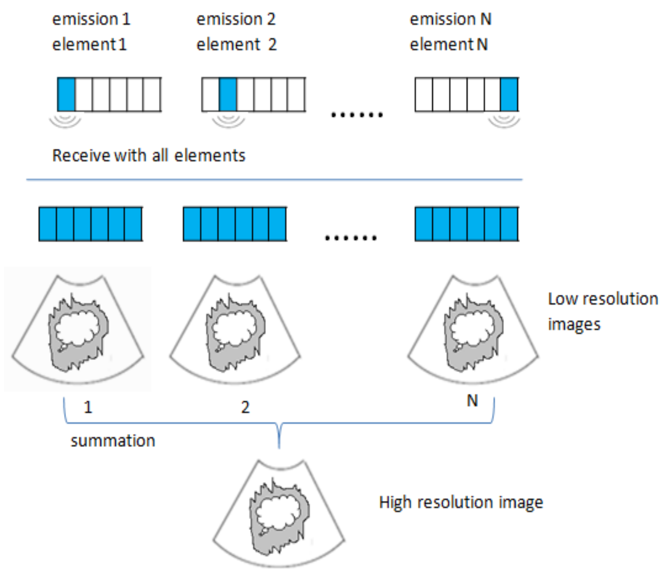


Fig.1.Genral model of Synthetic Transmit Aperture(STA)

1.Synthetic aperture focusing technique (SAFT) is a classical synthetic aperture method. At each time only a single array element acts as an active element for transmission and reception. It reduces system complexity, because only a single set of circuit for transmit and receive is needed. However it requires data memory for all data recordings.

2.Multi-element synthetic aperture focusing (M-SAF) is an alternate to SAFT . A group of elements transmit and receive signals simultaneously, and transmit beam is defocused to emulate a single element response. The acoustic power and thesignal-to-noise ratio are increased compared to SAFT where a single element is used. response. This method requires also memory for data recordings.

3.Synthetic transmit aperture (STA) is an alternate to conventional phased array. At each time one array element transmits a ultrasound pulse and all elements receive the echo signals. The advantage of this approach is that a full dynamic focusing can be applied to the transmit and the receive, giving the highest quality of image.

4.Synthetic receive aperture (SRA) was proposed to improve lateral resolution.At the same time, this method enables an imaging system to address a large number of transducer receive elements without the same number of parallel receive channels.

In above various synthetic aperture beam forming method we go for an synthetic transmit Aperture method. The Fig.2 shows a outlook of STA technique

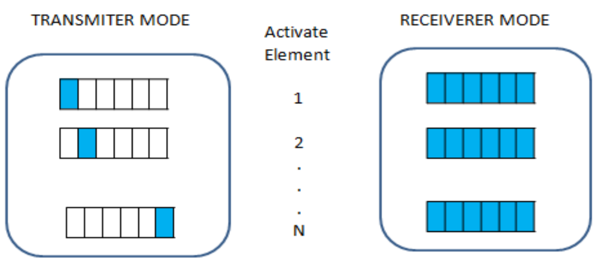


Fig.2.Synthetic transmit Aperture(STA) technique

IV. PROCEDURE

A. *Genral Systematic Outlook*

The genral project flow is shown in Fig.3.These give brief overview idea behind a project.The entire step by step process is included as

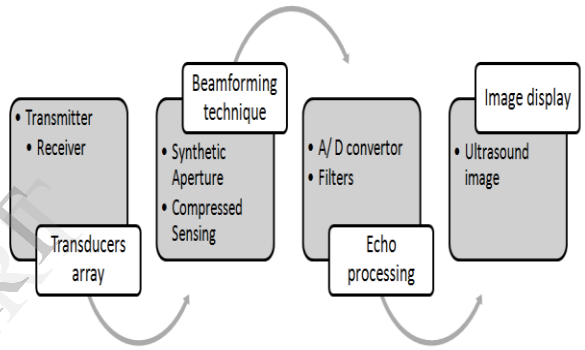


Fig.3. Genral System flow Diagram

Step 1: Design a transducer(Transducer/Receiver)
Step 2: Set a initial parameters such as sampling frequency, signal frequency
Step 3: Applying STA technique and compressed sensing to produce a ultrasound image
Step 4: Apply echo processing for proper scaling
Step 5: Display ultrasound image

V. EXPERIMENTAL RESULTS AND DISCUSSION

The simulation is done by using a Field II and beamforming toolbox. The computer system phantom for simulate ultrasound B-mode image is is created and it is used for processing. In general case an ultrasound imaging is done by using a linear array(LA) transducer with 128 elements and in that 64 element are made as active for transmitting signal. The initial focal distance(50mm) is set. The time taken for producing ultrasound B-mode image is more as compared STA technique. Initially a transducer is placed at a center position of phantom and it is excited by an impulse response and its various parameter are mentioned in Table.1. The Fig.4 shows the ultrasound image produced by a linear array imaging.

Table1.Parameters of linear array imaging system modeled by Field II

Parameter Name	**Linear array**	
	Notation	Value
No of transmit element	N_elements	64
No of receive element	N_elements	64
No of emission	N	65
Apodization	Hamming	
Central frequency	Fo	4 MHZ
Sampling frequency	Fs	100MHZ
Focus in transmit	Focus_r	50mm

In Conventional phased array(PA) imaging systems employ all elements of the transducer during both transmit and receive during each excitation cycle, while employing delays in order to steer the beam and scan a 2D plane. In the receive mode, dynamic (or composite) focus is used, by adjusting the delays of transducer elements as a function of the range (depth) at which the focusing is desired. In the transmit mode, usually the focus point is set in the middle of the depth being imaged. At the focus point, the lateral beamwidth is the smallest (and the best lateral resolution is therefore obtained) while away from the focus point, the lateral beamwidth increases. The Spatial resolution of ultrasound image formed by linear array imaging is reduced in Fig 4,these spatial resolution of the ultrasound image can be improved by using several transmit beams during the interrogation of each sector, each of which is focused at a different range of depths. Due to this the acquisition time for phased array(PA) imaging is increased.

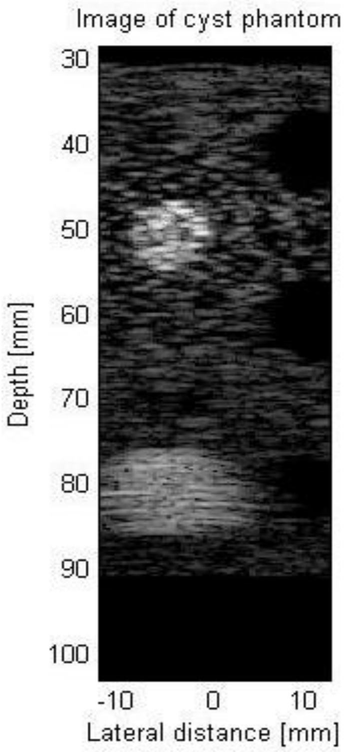
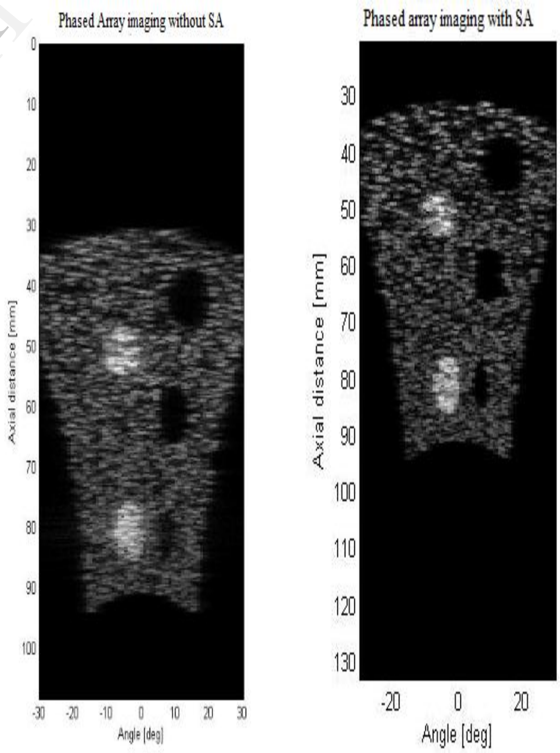


Fig.4.Cyst phantom by linear array imaging

Here we use an alternative way to obtain an appropriate spatial resolution, with a decrease in acquisition time, is to use the synthetic transmit aperture (STA) technique. This method makes it possible to generate images with dynamic focusing, during both transmit and receive, while maintaining or even drastically decreasing the acquisition time. In conventional STA imaging, a single transducer element is used to transmit, while all the elements receive the echo signals as shown in Fig 1. All the elements are excited sequentially one after the other, and the echoes received by all elements are recorded and stored in computer memory. Then all the echo data are focused synthetically by an appropriate algorithm. A disadvantage of an STA imaging system is the increased amount of the RFdata needed for image reconstruction. The major advantage of a STA imaging system is the significant decrease in the acquisition time of the data.

Comparing to phased array imaging, however, a significant increase in the frame rate of a STA imaging system is possible if and only if an equivalent time efficient algorithm is used for image reconstruction. Further, for better reconstruction from sparse signal the reconstruction is done by using a CS .The compressed sensing is genrally applied at a receiver for received rf data before the the beamforming is done.



(a) (b)

Fig.5.(a).Phased array imaging without Synthetic Aperture(SA), (b).Phased array imaging with Synthetic Aperture(SA).

Table.2.Parameters for Phased array imaging system modeled by Field II

Parameter Name	Phased array without STA		Phased array with STA	
	Notation	Value	Notation	Value
No of transmit element	N_elements	64	N_elements	64
No of receive element	N_elements	64	N_elements	64
No of emission	N	65	N	65
Apodization	Hannig		Hanning	
Central frequency	Fo	4 MHZ	Fo	4 MHZ
Sampling frequency	Fs	100MHZ	Fs	100MHZ
Focus in transmit	Focus_r	50mm	Focus_r	50mm
Steering angle	Sector	60 degree	sector	60 degree

Table.3.Acquisation time for various methods

Parameter Name	Linear array		Phased array without STA		Phased array with STA	
	Notation	Value	Notation	Value	Notation	Value
Acquisation time	t	35min 42 sec	t	23min 16sec	t	11min 19sec

VI. CONCLUSION

Synthetic transmit aperture (STA) imaging systems have been proposed as an alternative and advanced approach to the phased array systems and linear array system. As compare to linear and phased array imaging , STA produce better spatial resolution. In implementation, however, the frame rate of a STA imaging system depends not only on the acquisition time of the data but also on the processing time needed for image reconstruction. It is shown in the paper that the STA method sufficiently reduces only the time required for RF-data acquisition. Comparing to a phased array imaging system, it should be kept in mind that the significant increase in the frame rate of a STA imaging system is possible only if an equivalent time efficient algorithm is used for image reconstruction. On the other hand the RF data used for reconstruction is tremendously increased. Due to that data complexity increase at a receiver side. In order to reduce the cost as well as the acquiring data complexity sparse reconstruction is needed .For that in future the compressed sensing is applied at the receiver end for getting a better reconstruction from sparse signal.

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