Reflector Detection with Ultrasonic Array based on Encoded Transmission

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***Abstract*—This work approaches the design of an ultrasound sensory array based on Phased Array (PA) techniques, which allows the steering of the acoustic beam through the environment by electronics rather than mechanical means. The transmission of every element in the array has been encoded, according to Code Division for Multiple Access (CDMA), which permits multiple beam to be transmitted simultaneously. Together these features enable a parallel scanning system which does not only improve the image rate but also achieves high resolution ultrasound image in order to detect possible reflectors in the scanned environment.**

I. Introduction

Ultrasonic Phased Arrays techniques are an attractive method to show ultrasound imaging developed successfully in medical applications. Currently PA systems are applied in cardiac and abdominal diagnoses [1], where they have proven to be diagnostically useful and have enjoyed commercial success. Unlike most PA previous studies, in the current work PA techniques are used for airborne ultrasound imaging and the designed array will be on board a mobile robot in order to scan its surroundings.

In comparison with ordinary ultrasound single-element transducers, Phased Arrays transducers provide a fast method of beam steering without manual or mechanical scanner requirements. PA systems also offer a flexible way to reshape the beam pattern by changing the geometric parameters of the array, whereas single-element transducers require a change on its physical structure. Therefore single-element conventional transducers have a limited fieldwork.

One of the most remarkable advantages of PA is the beam steering without mechanical requirements. For this purpose the elements of the array are excited at programmed delay times [2]. Such delay schemes allow to steer the beam at any azimuthal angle, so that all the individual acoustic wavefronts are added to produce a maximum acoustic intensity along the steering angle.

On the other hand the main disadvantage of PA systems is its low image rate, because it depends on the number of image lines or sectors into which the image is divided, so if high resolution is needed, lower image rate will be achieved. From now on, image sectors will be referred as $\Delta K = \frac{S_e}{K}$, where S_e is the complete scanned section in the azimuthal plane and K the number of sectors into which the image of the environment is divided.

As a solution for the low image rate, different imaging techniques, such as Synthetic Aperture techniques (SA) [3], are developed in line with Phased Array techniques. In these Synthetic Aperture systems the image rate depends on how the signals are acquired. Hence the time needed to generate the whole image t_{image} does not depend on the number of sectors K but on the array size N. Consequently if $K > N$ the image rate of SA systems will be higher. However if the SA system transmits with a single element, the amount of energy emitted to the environment will decrease significantly. Likewise if the number of receivers is lower, the number of combined signals to obtain the whole final image will be lower than with PA systems.

The encoding of ultrasonic transmission has been already proposed in numerous previous works [4]; where different sequences and codes have been considered, such as Gold or Kasami codes, complementary sets of sequences, or LS (Loosely Synchronized) codes. In all these encoding schemes, the simultaneous emission and reception from different transducers is assumed, since every emitter has its own orthogonal code assigned to be discriminated. In this proposal a different orthogonal code C is assigned to each azimuthal angle sector ΔK, so that the direction of the received echo can be obtained. Furthermore, encoding provides higher SNR ratios, as well as immunity to noise.

In the current work a combination of PA and signal encoding techniques are used. To our knowledge, the new proposal lies in simultaneously steering the beam at different azimuthal angles by emitting $C = K\ LS$ codes at the same time, one for each image line or sector $\Delta K_i = 1 \dots K$. Transmitting more than one signal concurrently is usually precluded by the resulting interference between echoes. Nonetheless thanks to the encoded emitted signal properties, the sector ΔK_i from which the echo is received can be discriminated. Hence do not only higher image rates are achieved, but also the characteristics of conventional PA systems are preserved.

The manuscript is organized as follows. In Section II the array design is presented. Section III shows the proposed encoded transmission system to obtain ultrasound images of the environment. In Section IV simulation results are developed. Finally, conclusions are outlined in section V.

II. Proposed array

The proposed linear array and its main design parameters are shown in Fig. 1. It is made up of N elements, where D is the total lateral dimension, $L = 4cm$ is the element height,

$k_r = 1mm$ is the inter-element spacing, $w = 1.16mm$ is the individual element width, and $d = k_r + w$ is known as pitch. The size of pitch d must be $d \leq \frac{\lambda}{2}$ in order to avoid grating lobes which constitute peaks in the spatial response function of the array at angles differing from the main beam orientation. Since an echo imaging system should be sensitive only to targets positioned along the direction of the main beam, these grating lobe peaks reduce the dynamic range for unambiguous imaging. In [5] it is defined the critical pitch d_{cr} that avoids grating lobes for a maximum steering angle θ_{max} and wavelength λ (1). The dependence of the grating lobes on the pitch parameter d is depicted in Fig. 2.

$$d_{cr} = \frac{\lambda}{1 + sin(\theta_{max})} \quad (1)$$

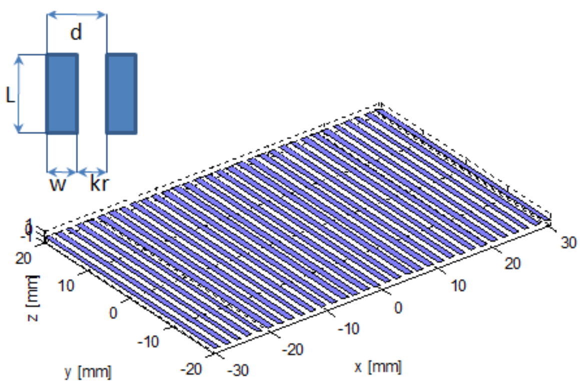

Fig. 1. Design of the proposed array.

Moreover, the number of elements N in the array determines the width of the beam as can be observed in Fig. 3. In the proposed array, the parameter N is equal to 32 elements, which has been chosen as a trade off between beam width and computational cost. All of them are used for transmission, however a single element is used to receive the echoes as will be explained in next section.

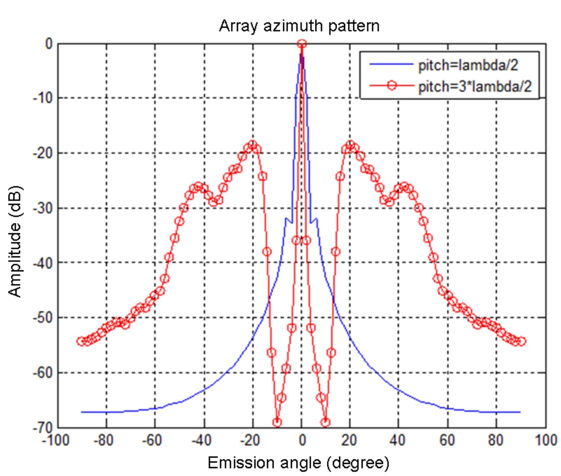

Fig. 2. Grating lobes with deflection angle $\theta = 0°$.

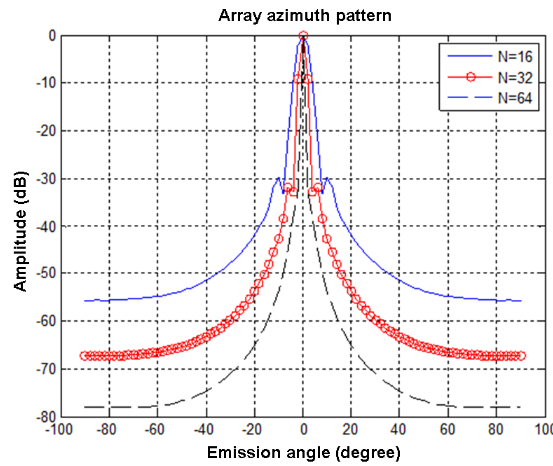

Fig. 3. Variation of the azimuth pattern according to the number of elements N.

The transducers or elements of the array will be manufactured by means of EMFi [6]. This material provides wide bandwidth and a plain response for common frequencies in ultrasonic applications [7]. Such properties are very appropriate for encoded ultrasonic signals in CDMA. Moreover EmFi shows more advantages over other technologies considering its use in ultrasonic applications:

- Low acoustic impedance ($Z \approx 0.03MRayls$), much closer to the air than the rest of the technologies used, so that it does not require adaptation stages.
- The material is presented in a thin film, due to its polymeric nature. Therefore it can be stuck to any kind of surface, making it easier to modify the emission-reception pattern of the transducer. [8].

III. Proposed Encoding System for Reflector Detection

In this work a different LS sequence C is emitted per each image sector $\Delta K = 1 \ldots K$ into which the image is divided. Unlike conventional PA systems, which needs a different emission for each image sector, this proposal allows to scan the whole environment S_e with a single emission. The acoustic beam will be steered simultaneously in $\Delta K = 1 \ldots K$ different directions and the receiver will be able to discriminate the direction from which the echo is received thanks to the AC and CC correlation properties of LS sequences (see Fig. 4).

Loosely Synchronized codes exhibit an Interference Free Window (IFW), where the aperiodic auto-correlation sidelobes and cross-correlation values become zero. Consequently, Inter-Symbol-interference (ISI) and Multiple-Access-Interference (MAI) are completely reduced if the maximum transmission delay is less than the length of the IFW.

The length of $IFW = 2 \cdot W_0$ depends on the total length of the LS code; for this reason a suitable code length LS must be chosen in order to remove the sidelobes from the scanned region. In the current application a code of $L_c = 16895$ bits and $W_0 = 511$ bits has been used allowing the system to detect

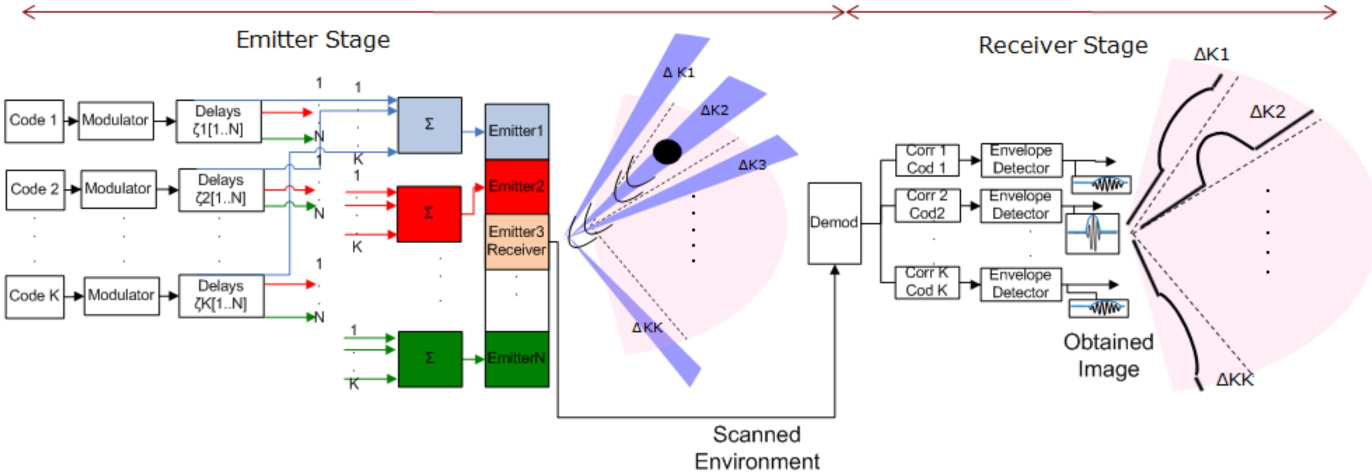

Fig. 4. Block scheme of the proposed encoding system.

reflectors at a maximum range of $1.5m$. In Fig. 5, LS CC and AC functions are shown for $L_c = 16895$ bits sequences, where $C = 32$ orthogonal sequences are available. This AC and CC properties will permit beams to be transmitted simultaneously while maintaining good signal separation and image quality in noisy environments.

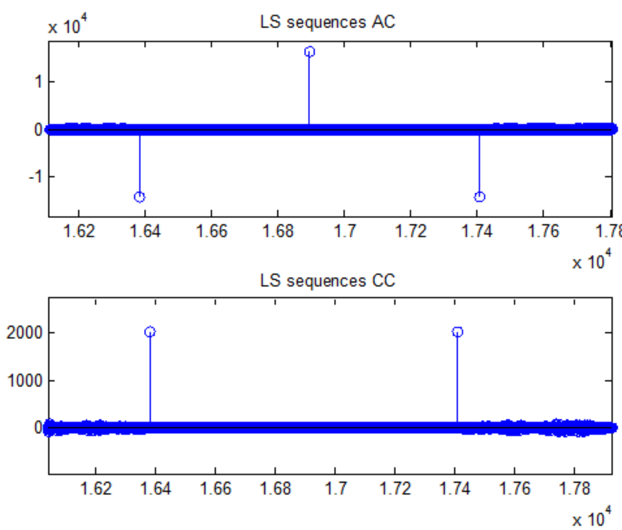

Fig. 5. AC and CC function for LS sequences of $W_0 = 511$ bits.

In Fig. 4 the block scheme of the proposed encoding system is shown, where at the emitter stage LS sequences are BPSK modulated (Binary Phase-Shift Keying) to hold the energy around the work frequency $f_0 = 80kHz$. The excitation of each element is the sum of $C = K = 32$ modulated sequences, each one with the appropriate delays for its steering angle $\Delta K = 1 \ldots K$. Hence 32 beams, steered in $\Delta K = 32$ different directions, are emitted simultaneously in order to explore the surrounded environment detecting reflectors.

At the reception stage, a single receiver has been considered. Once the received echo is demodulated, it is possible to obtain the signal for each scan-sector ΔK, into which the scanned environment S_e is divided $\Delta K = \frac{S_e}{K=32}$, by correlating the received echo with the original LS sequences. If a single reflector is placed in the second sector ΔK_2 (as depicted in Fig. 4) a correlation maximum will be obtained when the received echo is correlated with code $C2$, whereas the output of the rest correlators will significantly lower. Finally, the envelope is considered in order to depict the environment image.

As explained before, conventional Phased Array techniques need a different emission for each image sector. For each sector ΔK it is necessary to wait for the emitted signal to reach the remotest target and back $2 \cdot R_{max}$, which is referred as $t_{line} = 2 \cdot \frac{R_{max}}{c}$. Since the image resolution depends on the number of sectors $\Delta K = 1 \ldots K$ into which the image is divided, the time needed to generate the whole image S_e will be $t_{image} = K \cdot \frac{2 \cdot R_{max}}{c}$. Thus in ordinary Phased Array systems low image rate will be achieved for high resolution images. In the current work 32 beams, steered in $\Delta K = 1 \ldots K$ different directions, are emitted at the same time so that the whole environment S_e can be scanned with a single emission. Hence it is necessary only $t_{image} = t_{line} = 2 \cdot \frac{R_{max}}{c}$ and the processing time to generate the image maintaining the spatial resolution of the conventional PA.

IV. Results

Some simulated tests have been carried out to validate the proposed encoded emissions. In the following simulations a sector of $S_e = 64^o$ is scanned with a lateral resolution of $2°$; because as was explained before, the image is divided into $\Delta K = 1 \ldots 32$ sectors which is the number of available LS sequences with $W_0 = 511$ bits. It is possible to generate LS sets with more orthogonal sequences, however it implies longer lengths so a trade off must be settled. The frequency response of the transducer (EmFi) is considered in the following simulations, as well as a noisy environment with signal to noise ratio $SNR = 0$.

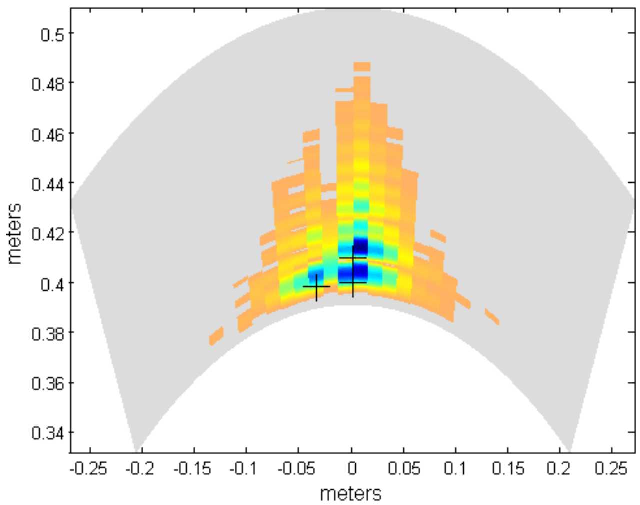

Fig. 6. Scan with reflectors at $R_1 = (40cm, 0°)$,$R_2 = (40cm, -5°)$ and $R_3 = (41cm, 0°)$.

In Fig. 6 the scanned image with punctual reflectors placed in $R_1 = (40cm, 0°)$, $R_2 = (40cm, -5°)$ and $R_3 = (41cm, 0°)$ is shown, where the real position of the reflector are depicted with crosses (+). It can be noticed how the proposed system can detect close reflectors in a noisy environment achieving a lateral resolution of $5°$ and a longitudinal resolution of $1cm$, when punctual reflectors are placed in a scanned sector of $S_e = 64^o$ with a single emission.

As the scanned sector S_e becomes wider, for a single emission, the image resolution decreases since the sector must be divided into $\Delta K = 1 \ldots 32$ parts; because only $C = 32$ LS orthogonal codes are available with $W_0 = 511$ bits. If lateral resolution has to be preserved, 2 sequential emissions (with 32 beams each one) must be launched for a scanned sector $S_e = 128^o$, and so on.

In Fig. 7 is shown how the proposed system can deal with several punctual reflectors. It must be pointed out how the lateral resolution decreases as the steering angle increases. For that reason, reflectors in $\theta = -15°$ seem to be wider than reflectors in $\theta = 0°$.

V. Conclusions

An ultrasonic sensory array has been defined, with a number of 32 elements, and a pitch $d = 1.16mm$ and a height of $L = 4cm$. The transmission at every element of the array has been encoded with a orthogonal LS code for each direction at which the beam is steered. This encoding permits 32 beams, steered in $\Delta K = 32$ different directions, to be transmitted simultaneously. The image generation rate, which turns out to be an important issue in real-time operation, is thereby increased in comparison with conventional PA systems. Furthermore, the properties of LS codes provide more immunity in noisy environments, and improved signal-to-noise ratios (SNR).

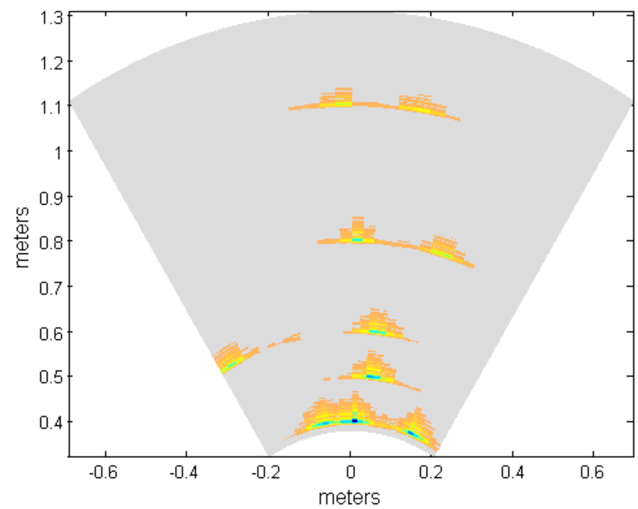

Fig. 7. Scan with 10 reflectors.

VI. Acknowledgements

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