Encoded Total Focusing Method for Improving Data Acquisition Rate

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Abstract: Synthetic aperture imaging techniques are capable to obtain high quality images, fully focused in both transmission and reception. However, these techniques require to perform so many emissions as elements in the array to acquire RF data. This requirement decreases acquisition rate and can result in tissue motion artifacts because of the phase misalignments between signals acquired in different emissions. Such inconvenience claims for alternatives that reduce the total number of emissions needed to obtain the data. This work proposes the use of Code Division Multiple Access (CDMA) techniques to attain this goal. By encoding the ultrasound excitation signal emitted, through a pesudo-random Kasami code, several elements can emit simultaneously and the amount of data acquired in every emission increases. The encoded proposal attains a Kx speed up in acquisition rate compared to conventional total focusing method, being K the number of Kasami sequences available in the set.

1 INTRODUCTION

The use of ultrasound imaging systems based on arrays has been widespread during the last decades, standing out as a safer and cheaper alternative to other imaging diagnosis techniques. Conventional Phased Array (PA) imaging systems fire all the elements of the array in every excitacion, acquiring a line of the image in every emission. The transmit beam must be prefocused so images obtained blur out of the focus. Synthetic Aperture Focusing Techniques (SAFT) represent an alternative to obtain fully focused images (Jensen et al., 2006). In the basic SAFT approach the transducer elements are activated sequentially acting as both transmitter and receiver. One signal per emission is acquired and stored in memory. Once every element has been activated and there are N signals in memory, a beamforming process is applied to dynamically focus, both in emission and reception, every pixel.

There are other SAFT approaches depending on the number of active elements used in transmission and reception. The SAFT method evaluated in this work is the Total Focusing Method (TFM) (Lockwood and Foster, 1995), where a single element acts as emitter and the echo data is recorded by the full array. One of the drawbacks of SAFT techniques is sensitivity to tissue motion during acquisition process. Since Radio Frequency (RF) data is obtained from multiple firings, motion artifacts may arise due to phase misalignments between data from different emissions. There are some solutions (Lokke Gammelmark and Jensen, 2003; Lokke Gammelmark, 2004) in the literature that propose motion compensation based on cross-correlation of reference signals to find the shift in position or phase of the tissue. These proposals are capable to estimate motion tissue in 2D, however their high computational cost is an inconvenience for real-time imaging sytems.

Another way to overcome motion artifacts is to reduce the acquisition time needed to form the image. In this regard, encoding techniques can allows us to achieve this goal by reducing the number of emissions needed to acquire the data.

Encoding techniques and pulse compression have been used in ultrasonic imaging mainly to enlarge penetration depth and to improve SNR without increasing the voltage excitation by using linear frequency modulation (FM)(O'Donnel, 1992; Toosi and Behnam, 2009). Some works have also studied the application of encoding through binary codes. (EMoo-Ho et al., 2002) propose Golay encoding to obtain signal to ratio (SNR) improvement without reducing frame rate. (Kim and Song, 2004) present a linear array emitting Golay codes in combination with chirp, achieving simultaneous multi-zone focusing along several scan lines. (Romero-Laorden et al., 2012) propose the use of Golay encoding in minimum redundancy SAFT solutions to overcome their limited SNR.

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Coded signals can be also used to differentiate simultaneous emissions. These techniques are known as Code Division Multiple Access (CDMA). CDMA have been successfully used for indoor positioning and obstacle detection in robotics applications (De Marziani et al., 2012; Diego et al., 2012; Klaus-Werner et al., 1998). In these works, a multi-user scenario is considered, assigning a different code to each user. Then simultaneous emissions and receptions from different users are possible, since each code is used as an user identifier.

Multiple access techniques have been already applied in ultrasonic imaging. (Shen, 1996) proposes to emit a pseudo-orthogonal m-sequence in each direction, acquiring several lines at the same time thanks to a bank of filters in reception stage. (Gran and Jensen, 2008) propose the use of pseudo-random codes in synthetic transmit aperture (STA) to separate the echoes originating from two different transmitters and improve SNR. Also (Diego et al., 2012) present a design of an ultrasonic phased array with *M* emitters and a single receiver based on encoded excitation with loosely synchronous sequences for obstacle detection, which scans the whole environment with a single emission.

This work suggest a new method based on using CDMA techniques in TFM imaging to reduce the emissions needed to acquire RF data. By encoding the transmission with pseudo-orthogonal Kasami codes several elements of the array can be excited simultaneously. Echoes coming back from the simultaneous emissions can be distinguished in reception thanks to the suitable correlation properties of the codes. Thereby the proposal allows to increase the amount of data acquired by a single emission, accelerating the acquisition process and making the imaging system less sensible to motion artifacts.

2 KASAMI SEQUENCES

Kasami sequences are widespread in CDMA techniques due to their suitable auto-correlation (AC) and cross-correlation (CC) functions. The small set of Kasami sequences used in this work is composed by $K = 2^{X/2}$ sequences of length $L = 2^X - 1$, where X must be even. If the length of the sequences increases, the number of sequences available also increases. However, as it was exposed (Gutiérrez-Fernández et al., 2014), in ultrasound imaging applications code length is limited due to the blind-zone problem. Therefore, 63 bits sequences are used in this work, which can be used to scan distances beginning from 5 cm. With this code length the Kasami set is composed by *K*=8 pseudo-orthogonal sequences. Generation of this Kasami sequences is based on the algorithm proposed by (Pérez et al., 2009), which allows to select those sequences with lower cross-talk values in asynchronous environments.

3 TOTAL FOCUSING METHOD

In Total Focusing method a set of *NxN* signals is used to obtain the highest image quality. A scheme of the acquisition process is shown in Figure 1. In every emission, a single element is fired and all elements receive echo data. For a *N*-element array this process is repeated *N* times, storing *NxN* recordings to compose the image. Once stored in memory, these recordings can be properly delayed to bring into focus all image points.

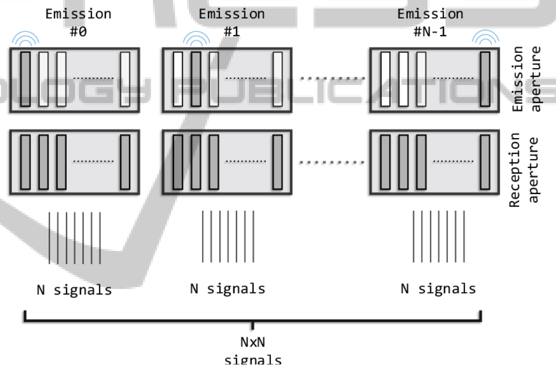

Figure 1: Acquisition process in Total Focusing Method for a 1-D *N*-element array. In every emission, a single element is fired and all elements receive echo data, acquiring *N* signals. This process is repeated for each array element, storing *NxN* recordings to compose the image.

TFM has the same T/R matrix and effective aperture than conventional PA (Lockwood and Foster, 1995), but it is fully focused, so the highest image quality is reached. Moreover, TFM reduces the electronics complexity in the emission stage by multiplexing the same electronic in every emission. However, as it has been aforementioned in section 1, TFM is affected by motion artifacts due to there are phase misalignments between signals acquired in different emissions. Therefore, it is clear that a reduction in the number of emissions needed to acquire RF data is desirable to properly scan fast moving tissues.

4 APPLICATION OF CDMA TECHNIQUES TO INCREASE FRAME RATE

The acquisition scheme of the proposal is shown in Figure 2, when a 1-D, N-element array and a set of K Kasami sequences, $C_0, C_1, \cdots, C_{K-1}$, are considered. In every emission there are K active elements, each one driven by a different Kasami code, $C_0, C_1, \cdots, C_{K-1}$. Orthogonality between codes assigned to each selected element makes possible that all of them can emit simultaneously. The elements activated in each emission are selected to maximize the separation among simultaneous emissions, since there is a separation of S-element between consecutive active elements. In reception, the full array is used to record N signals. Then, these signals are correlated with each one of the Kasami codes used in emission, allowing us to distinguish echoes received from the K simultaneous emissions. After correlation K groups of N signals are obtained and stored in memory. This process is repeated until the complete set of NxN signals to compose the image is obtained. Consequently, only $S = N/K$ emissions must be performed in this proposal, attaining a Kx speed up in frame rate (imag/sec) respect to the classical TFM technique, where N emissions are needed (Lockwood and Foster, 1995).

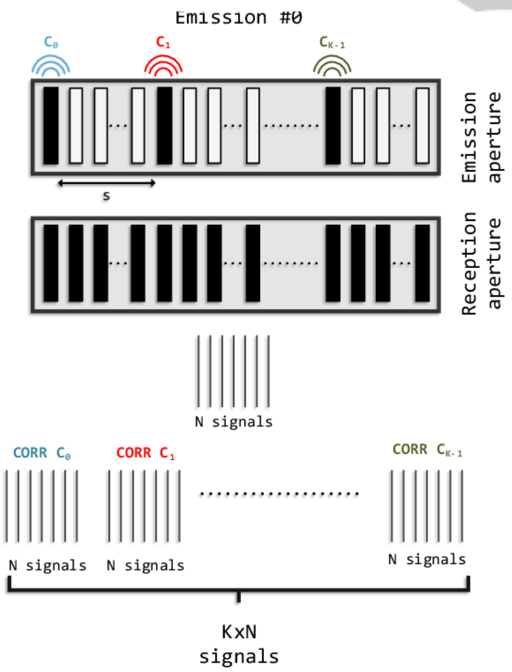

Figure 2: Acquisition process for one emission with the system proposed, combining CDMA and TFM techniques. A 1-D, N-element array and a set of K Kasami sequences, $C_0, C_1, \cdots, C_{K-1}$, are considered. There are K active elements in every emission, each one driven by a different Kasami code, $C_0, C_1, \ldots, C_{K-1}$. The full array is used in reception. KxN signals are acquired simultaneously in one emission. A correlation process between the N signals and the K codes emitted is carried out, obtaining KxN signals.

5 SIMULATION RESULTS

Different simulations have been carried out to analyse the advantages and drawbacks of the proposed technique in comparision with conventional TFM. An array with $N = 96$ punctual elements, a pitch of half wavelength and a frequency of 3 MHz are considered for both cases. In all simulations punctual elements with a flat frequency response has been considered.

A Gaussian envelope pulse with 80% of relative bandwidth has been considered as excitation for conventional TFM images. In the encoded proposal, the excitation signals are Kasami sequences with $L = 63$ bits, so the Kasami set is formed by $K = 8$ pseudo-orthogonal sequences. The sequences are BPSK modulated to adapt the codes to the working frequency of the transducer, a single carrier period per bit has been considered.

5.1 Contrast Resolution

Figure 3 shows the images obtained with conventional (a) and encoded (b) TFM proposals when a medium with a punctual reflector located at $r = 158$ mm and $\theta = 0°$ is scanned. Each image has a resolution of 64x1200 pixels and it is fully focused, both in emission and reception, in each pixel. The encoded approach presents a background noise in the reflector direction which reduces the image contrast in comparison with the conventional case. This background noise is consequence of the interference inherent to encoding techniques. The higher interference values are 25 dB under the maximum response, these values are mainly attributable to the AC interference.

5.2 Temporal Resolution

Conventional TFM needs to perform 96 emissions, one per array element, to obtain the whole set of NxN signals, while the enconded TFM requires only 12 emissions, therefore in the case shown in the figure 3 the proposal attains a 8x speed up in acquisition rate respect to conventional TFM. The reduction of the emissions needed to obtain RF data depends on the number of pseudo-orthogonal codes availables in the Kasami set. If the set is formed by K pseudo-orthogonal codes, K elements can be fired simultane-

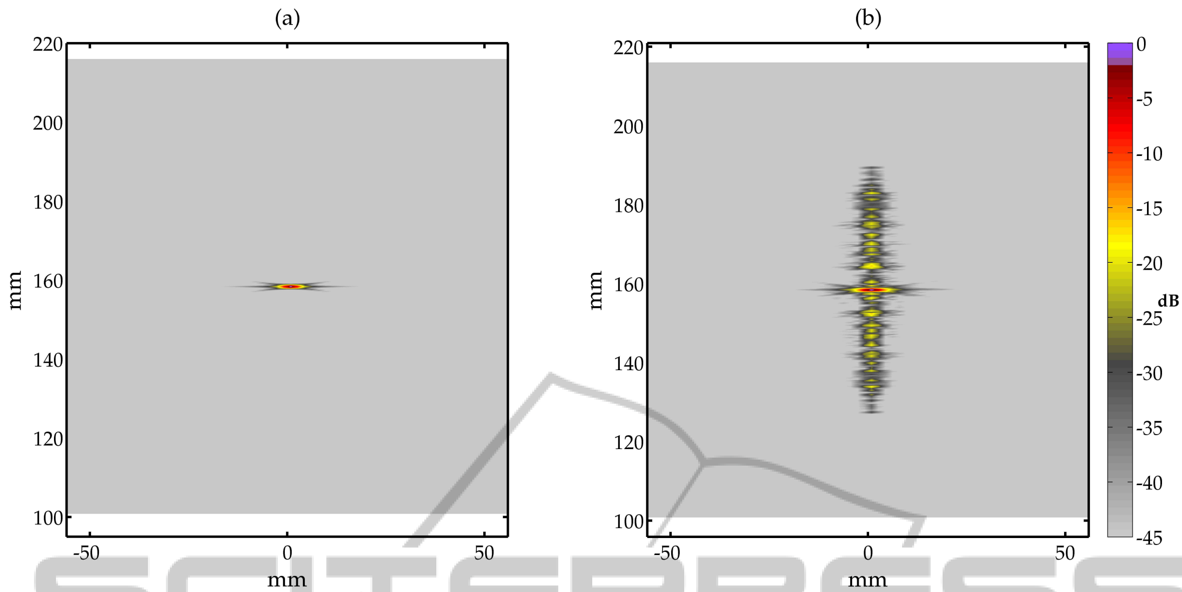

Figure 3: Images obtained with conventional (a) and encoded (b) TFM proposals when a medium with a punctual reflector located at $r = 158$ mm and $\theta = 0°$ is scanned. Each image has a resolution of 64x1200 pixels. An array with N=96 elements and pitch of half of wavelength is considered for both cases. Kasami sequences of L=63 bits are used to drive the elements in the encoded approach.

ously in a single emission, so Kx speed up is reached. This reduction in acquisition time can make the encoded TFM image system less sensible to motion artifacts and suitable to real-time applications.

6 CONCLUSIONS

This work has presented a proposal of synthetic aperture technique TFM in conjunction with CDMA to improve the acquisition rate. The central idea of the proposal is that emission from multiple elements simultaneously can be achieved by driving them with encoded signals, therefore, the RF data can be acquired with fewer emissions. The excitation signals used to drive the elements are a set of K pseudo-orthogonal Kasami sequences.

Simulation results have shown that inherent interference of Kasami encoding adds a background noise, reducing the image contrast respect to TFM reference image. Further studies will be conduced to minimize this interference by searching for other codes with better correlation properties or applying post-processing techniques.

The encoded TFM acquires the whole RF data in only N/K emissions, whereas conventional TFM requires N, one per array element. Consequently, a Kx speed up in acquisition rate compared to conventional method is attained. The improvement in acquisition rates can be greater if the number of pseudo-orthogonal codes available increases, since the number of elements that can emit simultaneously also increases. The solution presented stands as a promising alternative to make high quality TFM imaging systems less sensible to motion artifacts and capable to reach acquisition time requirements in real-time applications.

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REFERENCES

De Marziani, C., Ureña, J., Mazo, M., Hernández, A., García, J. J., Pérez, M. C., Aparicio, J., and Alcoleas, R. (2012). Simultaneous round-trip time-of-flight measurements with encoded acoustic signals. *IEEE Sensors Journal*, 12(10):2931–2940.

Diego, C., Martrín, C. J., Hernández, A., Jiménez, A., and Gutiérrez, C. (2012). Improved ultrasonic phased array based on encoded transmissions for obstacle detection. *IEEE Sensors Journal*.

EMoo-Ho, B., Woo-Youl, L., Mok-Kun, J., and Sung-Jae, K. (2002). Orthogonal golay code based ultrasonic imaging without reducing frame rate. In *IEEE Ultrasonics Symposium*, volume 2, pages 1705–1708.

Gran, F. and Jensen, J. (2008). Spatial encoding using a code division technique for fast ultrasound imaging. *IEEE transactions on ultrasonics, ferroelectris, and frquency control*, 55(1):12–23.

Gutiérrez-Fernández, C., Jiménez, A., Martrín, C. J., Hernández, A., and Ureña, J. (2014). A novel encoded excitation scheme in a phased array for the improving data acquisition rate. *Sensors*, 12:549–563.

Jensen, J. A., Nikolov, S. I., Gammelmark, K. L., and Pedersen, M. H. (2006). Syntethic aperture ultrasound imaging. *Ultrasonics*, 44:1–11.

Kim, B.-H. and Song, T.-K. (2004). Multibeam simultaneous transmit multizone (mb-stmz) focusing method using modulated orthogonal codes for ultrasound imaging. pages 315–323.

Klaus-Werner, J., Berg, M., and Müller, M. (1998). Using pseudo-random codes for mobile robot sonar sensing. In *3rd IFAC Symposium on Intelligent Autonomus Vehicles, Madrid, Spain*, pages 25–27. IAV.

Lockwood, G. R. and Foster, F. S. (1995). Design of sparse array imaging systems. In *IEEE Ultrasonics Symposium*, volume 2, pages 1237–1243.

Lokke Gammelmark, K. (2004). *Improving the Image Quality of Synthetic Transmit Aperture Ultrasound Images*. PhD thesis, Technical University of Denmark.

Lokke Gammelmark, K. and Jensen, J. (2003). Duplex synthetic aperture imaging with tissue motion compensation. In *IEEE International Ultrasonics Symposium in Honolulu, Hawaii*, volume 2, pages 1569–1573 Vol.2.

O'Donnel, M. (1992). Coded excitation system for improving the penetration of real-time phased-array imaging systems. *IEEE T Ultrason Ferr*.

Pérez, M. C., Ureña, J., Hernández, A., Jiménez, A., Ruí, D., Álvarez, F. J., and De Marziani, C. (2009). Performance comparison of different codes in an ultrasonic-positioning system using ds-cdma. pages 125–130.

Romero-Laorden, D., Martinez-Graullera, O., Martin-Arguedas, C., and Parrilla-Romero, M. (2012). Application of golay codes to improve snr in coarray based synthetic aperture imaging systems. In *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2012 IEEE 7th*, pages 325–328.

Shen, J. (1996). A new coded-excitation ultrasound imaging system. *IEEE Transanctions on Ultrasonics, Ferroelectrics, and Frecuency Control*, 43(1):131–140.

Toosi, T. K. and Behnam, H. (2009). Combined pulse compression and adaptive beamforming in coded excitation ultrasound medical imaging. In *International Conference on Signal Processing Systems*.