PONS for Covert, Robust and Computationally Efficient Transmission of Digital Signals

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Sets of orthogonal waveforms having energy spread uniformly throughout their effective time-bandwidth extent are well suited for communications applications requiring robustness to significant noise and transmission loss. Further, real-time low-bandwidth communications require fast algorithms that use minimal computational power and memory while simultaneously yielding a high rate of data compression. Finally, if security is an additional requirement, then the algorithms must also be amenable to real-time encryption and decryption.

PONS [3] comprises a transform coder and decoder for discrete time signals. The PONS coder utilizes an integer coefficient transform coder which is not frequency based, which requires exclusively fast integer arithmetic, has a N log N decomposition (similar to FFT), and which spreads incoming signal energy nearly as evenly as possible among coefficients in the transform domain. The PONS coder also has the property that the magnitudes of transform domain coefficients vary by less than about an order of magnitude, so that the PONS coder dispenses completely with coefficient-dependent bit allocation. If compression is desired, PONS uses only the quantization step to achieve this. As will be seen, energy spreading also permits reasonably accurate signal reconstruction even when significant numbers of transform coefficients are lost or corrupted.

Moreover, energy spreading makes the transmitted PONS domain version of the signal appear to be white noise, thus naturally adding security to the communications system. Additional security may be incorporated by permuting the order of the PONS basis elements, which is also a real-time operation. While it is well known that such a straightforward encryption scheme can be broken by using relatively sophisticated hardware and/or software, for field operations where time is of the essence and computational power is likely very limited, this basis scrambling combined with the natural apparent randomness of the PONS domain representation of the signal should prove sufficiently secure.

It is straightforward to describe, in heuristic terms, what we mean by "energy spreading." Namely, when a digital signal of any dimension is expanded in the PONS basis, each of the terms in the transform domain has approximately the same amount of energy. Various mathematical details may be found in publications including [1], [2] and [4].

We illustrate several of the above properties via an image processing example, using Figure 1 as our sample digital image. Figure 2, which appears to the eye to be white noise, is a PONS representation of Figure 1 containing exactly the same information as the original (since the PONS transform is invertible).

Suppose there is some kind of bursty noise which substantially degrades transmission of Figure 1 at isolated and unpredictable times. Figure 3 is an example of such a situation, where roughly 60% of the pixels have been lost.

Now suppose that the PONS transform has been applied before transmission, so that Figure 2 is transmitted in place of Figure 1. If the same exact burst error occurs during transmission as did with Figure 2, Figure 4 is received. However, when the inverse PONS transform is applied to Figure 4, Figure 6 results. Comparison of Figures 3 and 6 show a main advantage of energy spreading. Figure 1 is repeated as Figure 5 for easy comparison of the PONS reconstruction for 60 % pixel loss with the original (no pixel loss).

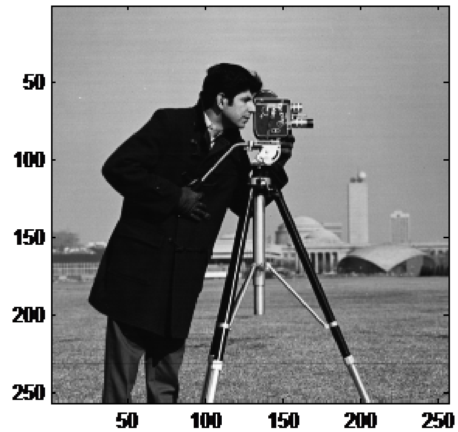

Figure 1: Original Image

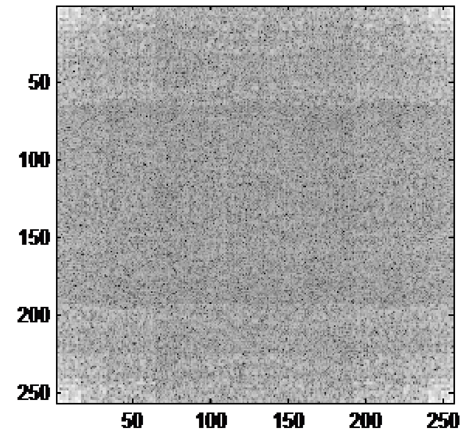

Figure 2: PONS of Original Image

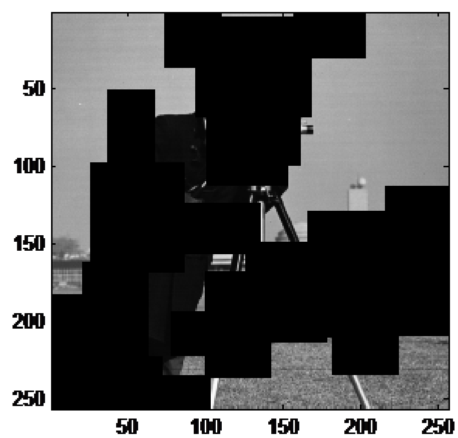

Figure 3: Image after 60% Loss

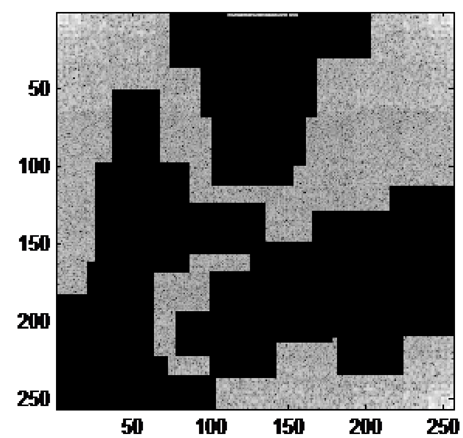

Figure 4: PONS after 60% Loss

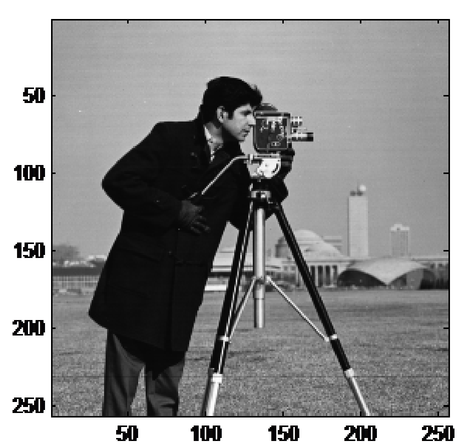

Figure 5: Original Image (Again)

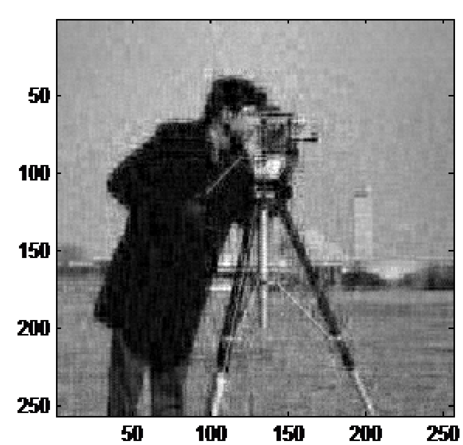

Figure 6: Reconstructed PONS of 60% Loss

In more general terms, no matter which PONS terms were lost because of such noise, there would be only very gradual signal degradation (*i.e.,* slightly more degradation with each term that is lost). For all other known transforms (wavelet, DCT, Walsh-Hadamard, *etc.*), if low energy terms were lost because of such noise there would also be very little signal degradation, but if even one high energy term was lost the degradation would probably be quite substantial.

Please contact Prometheus President Jim Byrnes (jim@prometheus-us.com) for details regarding PONS-based algorithms and licensing.

References

[1] J.S. Byrnes, "Quadrature mirror filters, low crest factor arrays, functions achieving optimal uncertainty principle bounds, and complete orthonormal sequences – a unified approach," *Applied and Computational Harmonic Analysis*, vol. 2, pp. 261–266, 1994.

[2] J.S. Byrnes, "A low complexity energy spreading transform coder," *Proc. 1994 Conf. on Image Processing*, Haifa, Y. Zeevi, Ed., 1996

[3] J.S. Byrnes, M.A. Ramalho, G. Ostheimer, and I. Gertner, Discrete one dimensional signal processing method and apparatus using energy spreading coding. U.S. Patent #5913186, 1999.

[4] J.S. Byrnes, B. Saffari and H. S. Shapiro, "Energy Spreading and Data Compression Using the Prometheus Orthonormal Set," *Proceedings of the 1996 IEEE Digital Signal Processing Workshop*, Loen, Norway, 1996.