Correlation Integral Analysis of radar sea clutter *

C.P. Unsworth, M.R. Cowper, S. McLaughlin, B. Mulgrew
Signals and Systems Group,
Department of Electronics and Electrical Engineering,
University of Edinburgh, The King's Buildings,
Edinburgh, EH9 3JL, Scotland, UK

Email : sml@ee.ed.ac.uk
Tel : (+44)-131-650-5578, Fax : (+44)-131-650-6554

ABSTRACT

This paper examines radar sea clutter data using the correlation integral. The properties of the sea clutter data sets are investigated for different polarisation, range gates, data length, wind speeds and also for pulse compressed and non pulse compressed data.

1 Introduction

Conventionally, high resolution radar sea clutter has been modelled by a stochastic compound k-distribution[1]. Recently, Haykin et al.[2][3] have analysed several sea clutter data sets using nonlinear techniques. Their results have suggested that sea clutter is generated by an underlying chaotic process.

An alternative method is proposed to determine the nature of sea clutter. The examination of the behaviour of the correlation dimension (d_2) drawn from the correlation integral (C(r)) of Grassberger et.al. for increasing embedding dimension (d_E) is robust at distinguishing white and correlated stochastic times series from deterministic ones. Therefore, it is suggested that such a method is used first to determine the nature of an unknown system.

2 Use of the correlation integral

The correlation integral(C(r)) method introduced by Grassberger and Procaccia [4] does not assume any structure about the system under study. Essentially, it performs a measurement of the distances between every pair of vectors that exist in the dataset and reports a log probability density function (pdf) of the result. It is a well documented and frequently used measure for obtaining d_2. This is achieved by the examination of d_2 for increasing embedding dimension(d_E). If the system is deterministic its attractor will occupy space in and up to the embedding dimension that it exists in. In dimensions greater than d_E no more space will be occupied by the attractor. This will be evident in the measurement of d_2 for increasing d_E. As d_E increases, d_2 will increase until a plateau onset occurs which will cause d_2 to saturate at the embedding dimension that the attractor exists in.

3 Measuring the correlation integral

The behaviour of the correlation integral has been studied in considerable detail and in [5] a thorough survey of the sources of error that can arise in the correlation integral was presented. The paper documents how poor statistics can occur for small distances(r) due to finite data length; how poor estimation of C(r) at values of r that are very much less than some value σ result due to the effect of noise on an attractor; how stair-like behaviour on the C(r) plot can result due to decimal precision of the data or discretization; how intrinsic oscillation of C(r) results, otherwise termed as lacunarity, which inhibits the accurate determination of slope and how an anomalous shoulder in C(r) can arise due to autocorrelation in a time-series,

A concern relating to the calculation of the correlation integral for stochastic systems by Osborne and Provenzale[6] reported that coloured random noise characterised by a power law spectrum can produce a plateau onset and thus a convergence of the correlation dimension. Theiler demonstrates mathematically that such issues can be corrected by introducing an autocorrelation correction into the Grassberger algorithm that excludes all pairs of points closer together in time than the autocorrelation length(τ) and by using very long data lengths(N) for an embedding dimension(m), where $N > 2\tau^{m/2}$. Such a correlation algorithm incorporating the autocorrelation correction of [7] is used here. The sea clutter sets analysed here are very long as is suggested in [8].

4 Behaviour of d_2 versus d_E for pulse compressed radar sea clutter

The sea clutter sets were taken from two pulse radars which used pulse compression [9]. The radar parameters for the two sets are given in Table 1. The Portland data was taken from a stationary land-based radar which pointed out to sea. The Wavetank data was taken

---

* This work was supported by BAE Systems, DERA Malvern, EPSRC and the Royal Society. Sea clutter data was provided courtesy of S.Lycett and W.Dawber of DERA, Malvern.

from a radar situated in a large wavetank laboratory. Data sets of 200,000 points were taken from each radar which corresponds to 3.3 mins temporally. 10,000 reference points were used in the calculation of C(r). The effect of the variation of range gate, polarisation, data length and windspeed on the behaviour of the d_2 versus d_E plots were then examined.

Parameter	*Portland*	*Wavetank*
Frequency	X-band	15.75GHz
Pulse compression	Freq.chirp	39ns Freq. chirp 500MHz BW
Resolution	0.3m	0.3m
Beaufort scale	3(Gentle Breeze)	6(Strong Breeze)
Polarisation	HH	HH
PRF	1kHz	1kHz
Grazing angle	small	6^o
Beamwidth	small	5^o
No.datapoints	200,000	200,000
No.ref.points	10,000	10,000

Table 1 : Radar parameters of sea clutter sets

4.1 Behaviour of d_2 versus d_E for I,Q and amp data

The polarisation of the sets was horizontal on transmit and receive (HH). The results are shown in Figure 1. It can be seen that the behaviour of the d_2 versus d_E plots for both sea clutter sets for the various channels are the same. They exhibit the characteristic that is evident of either a white or correlated stochastic system.

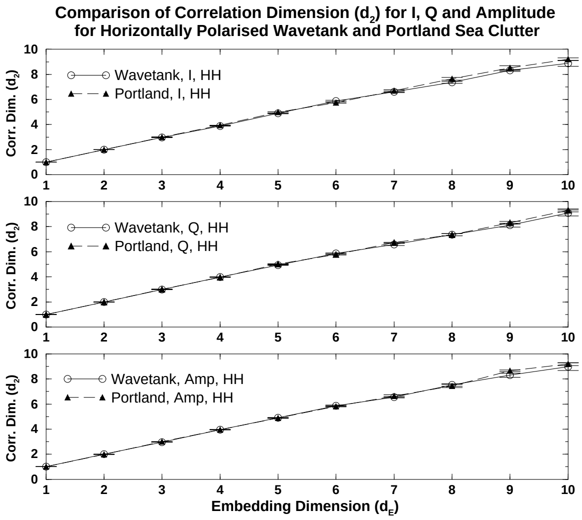

Figure 1:

4.2 Behaviour of d_2 versus d_E with Polarisation

Figure 2, highlights that there is no change in the behaviour of d_2 versus d_E for both HH and VV polarised clutter.

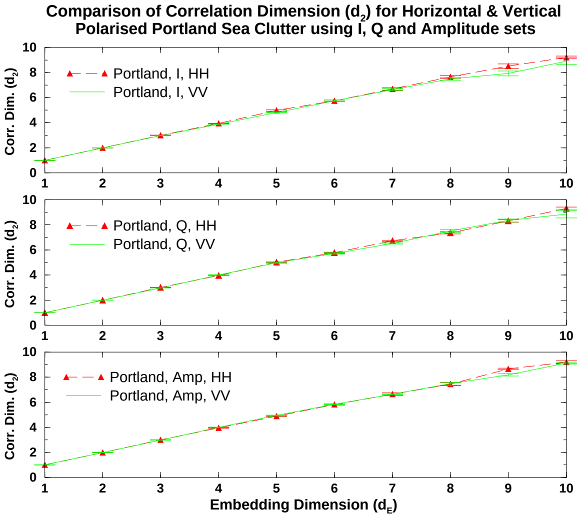

Figure 2:

4.3 Behaviour of d_2 versus d_E with data length

The behaviour of d_2 versus d_E was then investigated for variations in data length. New data sets were drawn from the Portland and Wavetank clutter sets with lengths of 25000, 50000, 100000, 150000, 200000 samples. Figure 3, shows the behaviour for the Portland VV polarised I channel. Figure 4, shows the behaviour for the Wavetank HH polarised I channel. From the results of Figures 1 and 2, we would expect the behaviour to be the same for Q, amp, and HH & VV polarisations. Figures of 3 and 4 display the same behaviour as. It can be seen that a slight shoulder appears for $d_E \geq 8$ for the clutter sets with a low data length $\leq$50,000. This can be explained, by the fact the plots become linear at data lengths $\geq$100,000. In other words, it implies that not enough data was available to make an accurate measurement at high dimensions of the C(r). Therefore, the estimate of d_2 becomes inaccurate which in turn affects the linearity of the graph.

4.4 Behaviour of d_2 versus d_E for Windspeed

Wavetank data sets were recorded whereby the windspeed used during the collection of the clutter data could be altered. Windspeeds of 4, 6, 8, 10 and 12m/s were used to collect sea clutter data. However, only data lengths of 30,000 samples were recorded. From the data length results of Figures 2 and 3, it was found that a shoulder might become evident at high dimensions for low data lengths as evidenced in Figure 5. No evidence of saturation of the embedding dimension was observed for the pulse compressed sets to suggest that they were generated by a chaotic process.

5 Non Pulse Compressed Sea Clutter

The data sets were taken from a land based radar that pointed out to sea. Two data sets were taken from the same radar at different pulse repetition frequencies (PRF) and windspeeds. Data lengths of 400,000

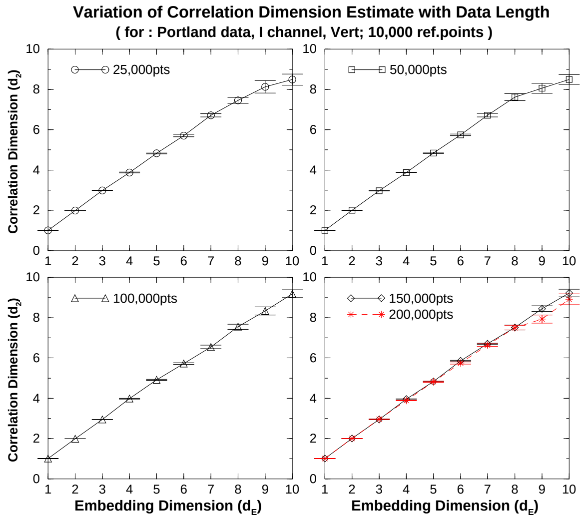

Figure 3:

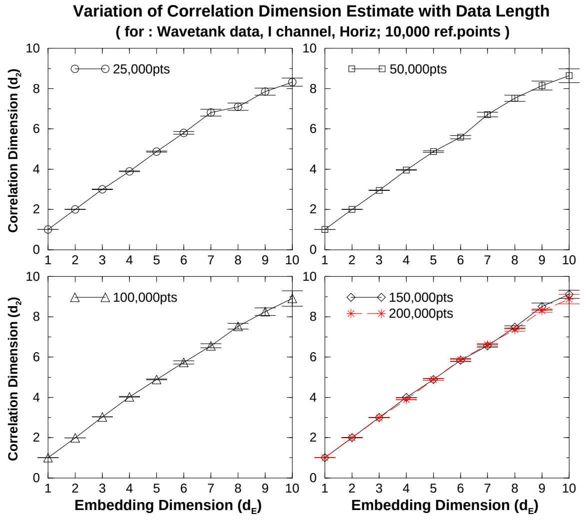

Figure 4:

samples were recorded which corresponded to 16 and 40 seconds temporally for the respective PRF's of 25kHz and 10kHz used. Table 2 illustrates the parameters of the radar used in the data collection process.

Parameter	*Dawber 3322*	*Dawber 3537*
Frequency	3GHz	3GHz
Pulse compression	Not used	Not used
Resolution	$1\mu s$	$1\mu s$
Windspeed	11.3m/s	16.4m/s
Polarisation	HH	VV
PRF	25kHz	10kHz
Grazing angle	0.43^o	0.24^o
No.datapoints	400,000	400,000
No.ref.points	5,000	5,000

Table 2 : Radar parameters of Dawber sea clutter sets

The correlation integrals of the sets are shown in Figure 6. Figure 8 illustrates d_2 versus d_E for the same data set. In both cases 5,000 reference points were used in the calculation of the integral.

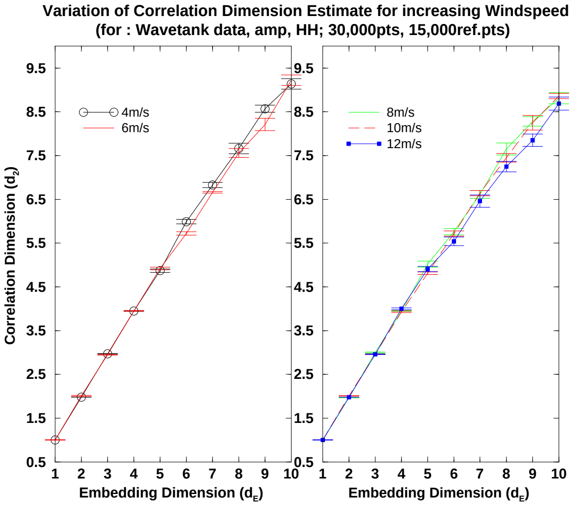

Figure 5:

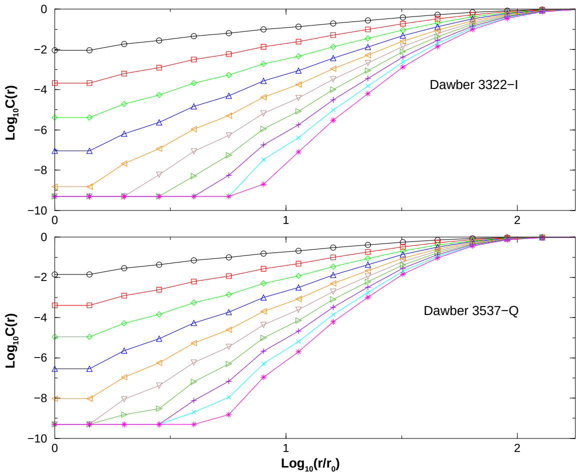

Figure 6:

Thus, the same behaviour is reported here for the non pulse compressed data as was found for the pulse compressed data of section 4. No evidence of saturation of embedding dimension was found for these sets.

6 Conclusions

A number of real radar sea clutter sets were examined using the correlation integral method with autocorrelation correction suggested by Theiler. Non pulse compressed data was then examined and the behaviour could be attributed to a white or correlated stochastic system, as was found for the pulse compressed data.

References

[1] Watts.S., Baker.C.J., and Ward.K.D., "Maritime surveillance radar part 2: detection performance prediction in seaclutter," *IEE Proc. Part F.*, vol. 137, pp. 63–72, 1990.

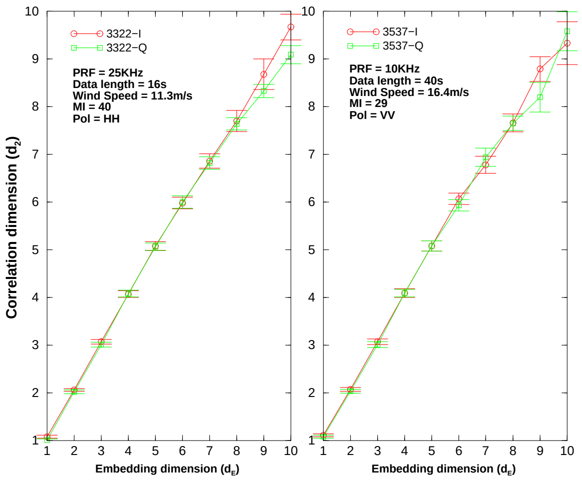

Figure 7:

[2] Haykin.S. and Li.X.B., "Detection of signals in chaos," *Proc.of IEEE*, vol. 83, pp. 95–122, 1995.

[3] Haykin.S. and Puthusserypady.S., "Chaotic dynamics of seaclutter: an experimental study," *Proc.of IEE Radar 1997*, pp. 75–79, 1997.

[4] Grassberger.P. and Procaccia.I., "Measuring the strangeness of strange attractors," *Physica 9D*, pp. 189–208, 1983.

[5] Theiler.J., "Estimating fractal dimesion," *J.Opt.Soc.Am.A*, pp. 1055–1073, June 1990.

[6] Osbourne.A.R. and Provenzale.A., "Finite correlation dimension for stochastic systems with power-law spectra," *Physica D*, vol. 35, pp. 357–381, 1989.

[7] Theiler.J., "Some comments on the correlation dimension of $1/f^\alpha$ noise," *Physics letters A*, pp. 480–493, 1991.

[8] Theiler.J., "Spurious dimension from the correlation algorithms applied to limited time-series data," *Physical Review A*, pp. 2427–2432, 1986.

[9] Skolnik.M.I., *Radar Handbook.* McGraw-Hill, 1970.