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Book Review

A. Hirose, Complex-Valued Neural Networks, World Scientific, Singapore, ISBN 981-238-464-2, 981-238-561-4 (Paperback), 2003

This is a rather specialised book, even by the usual technical literature standards. My own experience with neural networks extends only to applications of the usual real-valued structures and I may not be the most apposite reviewer; however, I will at least present an opinion from the point of view of a regular Journal of Sound and Vibration reader and contributor. The book is an edited volume with 15 chapters ranging over the theory and applications of complex-valued neural networks. The book covers a lot of ground and while it is not usually good practice to present a book review as a chapter-by-chapter description, this seems the most appropriate course of action here. The general trend in the book is from theory to application; however, there are deviations from this general rule. One remark I might make is that although I read this book from cover to cover, this might not be the best way to approach it, particularly as the applications come from a wide range of fields and their chapters sometimes require nontrivial specialist knowledge.

The book opens with *Complex-Valued Neural Networks: An Introduction* by A. Hirose. This is a very short chapter which attempts to do no more than motivate the study of complex-valued networks. As one might expect, these are largely traditional neural network paradigms generalised to allow complex weights and activations. One argument in favour offered by the author is that nature is fundamentally complex because of the role of the imaginary i in quantum mechanics. Another argument which is likely to be more compelling to the readership of JSV is that complex data are commonly encountered in the frequency domain.

The second chapter is the first of the technical chapters proper. This is *Orthogonal Decision Boundaries and Generalization of Complex-Valued Neural Networks* by T. Nitta. This is concerned with the classification problem in pattern recognition, in which decision boundaries play a fundamental role. The main thesis of the chapter is that decision boundaries which intersect orthogonally lead to improved network generalisation. The chapter makes clear the differences between real and complex neural networks by analysing their fundamental properties from the point of view of network architecture. Complex back-propagation is discussed as the steepest-descent algorithm for complex neural networks. In such a short chapter it is not possible to present rigorous arguments and this results in some of the arguments being a little unconvincing.

The next two chapters are concerned with complex-valued associative memories. These are generalisations of the Hopfield network which was largely responsible for the resurgence of interest in neural networks in the early 1980s. The first chapter of the pair is: *Complex-Valued Neural Associative Memories: Network Stability and Learning Algorithm* by D.-L. Lee. The

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chapter discusses Hopfield networks modified to have complex weights and activations. A number of results on recall and fixed points are proved. Three learning rules are reviewed: the generalised Hebb rule (GHR), the pseudoinverse rule (PR) and modified gradient descent (MGR). It is shown that the MGR rule leads to better network capacity that the GHR and also to better error correction. Chapter four continues the theme with *A Model of Complex-Valued Associative Memories and Its Dynamics* by Y. Kuroe. This concentrates on a particular type of associative memory (AM)—the correlation type. In a standard AM, patterns are stored as fixed points of the iteration. The novelty of the complex AM is that the fixed points need not be isolated as they are in the standard real-valued structure. In order to investigate the stability of the fixed points, centre manifolds are used to investigate behaviour of solutions in the neighbourhood of fixed points. A condition is given for each memory to be correctly recalled and this is validated by numerical experiment.

The fifth chapter is *Clifford Networks* by J. Pearson. This is concerned with a further generalisation which allows weights and activations to take values in a Clifford algebra. The basic definitions of Clifford Algebra are given and the backpropagation algorithm for Clifford-valued networks is presented. The main result is that Clifford networks are proved to be universal approximators.

The next chapter returns to the AM with *Complex Associative Memory and Complex Single Neuron Model* by I. Nemoto. This contrasts the large-scale complex AM with the small-scale Nagumo-Sato model of a single neuron. The application here is to treat the timing or phase of impulse trains. First, it is argued that complex values allow better separation of dichotomies (two-class problems) in a complex perceptron. The complex AM is then built from a number of parallel complex perceptrons. It is shown (by numerical simulation) that the average attractivity of patterns is improved over the real case by more than a factor of two (one might expect a factor of two from the fact that the parameter count is doubled). The discussion moves on to the complex Nagumo-Sato model and presents an analysis of the orbits of the model which can exhibit chaos. The dynamical systems analysis is very technical and makes considerable demands on the reader.

The book carries on with the theoretical viewpoint with a *Data-Reusing Algorithm for Complex-Valued Adaptive Filters* by D.P. Mandic, S.L. Goh and A. Hanna. This chapter is motivated by recent interest in complex-valued adaptive filters as a means of processing complex-valued signals like those arising in satellite communications. It is argued that data-reusing (DR) can speed up gradient-based algorithms for adaption while minimising the additional computer overheads. A complex linear adaptive filter is proposed which extends the standard LMS algorithm to complex-valued signals. This complex LMS algorithm, which is gradient-based, is further extended by DR. Finally, the DR approach is also applied to complex *nonlinear* adaptive filters, leading to two new algorithms which show improvements in speed of convergence.

Chapter eight is *Instantaneously Trained Neural Networks with Complex Inputs* by P. Rajagopal and S. Kak. This generalizes the corner classification method of instantaneous training to the case of complex inputs. The weights are assigned based on the inputs—there is no computation. A new algorithm, the 3C (complex corner classification) algorithm is presented. The algorithm is very simple and demonstrated on a modified XOR problem, a pattern recognition example and also on a Mackey-Glass time-series prediction. The generalisation capacity of the networks is shown to be reasonable.

The next chapter title speaks for itself—*Applications of Complex-Valued Neural Networks for Image Processing* by H. Aoki. A complex associative memory (CAM) is once more employed, this time for recovering images. The complex neuron is used to represent a grey-scale for the image by allowing pixels to take values on the unit circle (i.e. phase values). The amplitude information from the image is embedded in the phase and the resulting phase matrix is stored in the CAM. Two examples are discussed: an image filtering problem and recall from a noisy version of a stored image.

The next chapter departs somewhat from the prevalent engineering examples and considers the storage of music—*Memorisation of Melodies using Complex-Valued Recurrent Neural Networks* by M. Kinouchi and M. Hagiwara. This is example of the problem of dealing with temporal sequences, in this case, melodies. A new learning algorithm for complex-valued recurrent networks is proposed—Complex Backpropagation for Temporal Sequences (CBPT). The recurrent network is necessary because the usual CAM structure is only suitable for storing patterns rather than sequences. An architecture—the MUSIC (MUltlayer network for Sequential Inputs using Complex neurons)—is proposed and is shown to outperform an Elman network. To store many melodies, the authors propose the use of multiple small MUSICs rather than one large one.

Chapter 11 concerns the *Complex-Valued Generalised Hebbian Algorithm and its Application to Sensor Array Signal Processing*, and is written by Y. Zhang. The main concern is principal component extraction as a means of feature extraction and data compression. The Generalised Hebbian Algorithm (GHA) is already used to extract principal components in the case of real data. In the situation—as in sensor array signal processing—where complex signals occur, the algorithm requires generalisation and in this chapter the authors present the complex GHA (CGHA). The approach is illustrated through the problem of Direction of Arrival (DOA) estimation.

Another applications chapter follows with the *Phasor Model with Application to Multiuser Communication* by T. Miyajima and K. Yamanaka. In an earlier chapter, neurons were introduced whose states took values on the unit circle—*phasor models*. The authors here generalise the phasor model to also allow states taking values at the origin—so-called resting states. They also establish the stability of the new model. Despite the minimal modification, the authors show that the new model gives improved performance for a multiuser detector.

The 13th chapter is concerned with *Adaptive Interferometric Radar Image Processing by using Complex-Valued Neural Networks* and is written by A.B. Suksmono and A. Hirose. Synthetic Aperture Radars produce amplitude and phase information i.e. complex data, and require appropriate signal processing. In this study, the image is modelled as a comple-valued Markov random field (CMRF). This CMRF is embedded in a lattice neural network—CMRF-LNN—in order to manipulate the images e.g. for phase noise filtering and image restoration. The new technique is shown to lead to improvements in phase unwrapping.

The penultimate chapter is concerned with a *Complex Neural Network Model with Analogy to Self-Oscillation Generated in an Optical Phase-Conjugate Resonator*, and is by M. Takeda and T. Kishigami. The study demonstrates a complex-valued neural network with dynamical analogues to self-oscillation generated in an optical resonator. It is motivated by the possibility of an all-optical implementation of a neural network. Simulations of neural fields produced by the model give physically reasonable results when compared with optical fields in phase-conjugate resonators.

The final chapter discusses *Coherent Lightwave Neural Network Systems: Use of the Frequency Domain* and is written by S. Kawata and A. Hirose. In this chapter, optical neural networks make an appearance again, as do CAMs and complex Hebbian learning.

Overall, the book presents a wide range of viewpoints relating to complex-valued neural networks. This is both a strength and a weakness. The book would appear to give fairly complete coverage of the field and for a reader interested in exploring the literature there are many references. However, the coverage lacks depth, particularly in the rather terse applications chapters. As far as the readership of JSV is concerned, the book concentrates rather too much on complex associative memories which are scarcely used in vibrations and acoustics research. More familiar architectures are the multi-layer perceptron (MLP) and radial-basis function (RBF) networks; the first of these is discussed a little, the second not at all. (This may simply because there is no sensible implementation of the complex RBF, this reviewer is not familiar enough with the field to say.) Given that specialists in signal processing, vibrations and acoustics spend much of their time in the complex plane, they may find that this book is worth locating in their library and dipping into; I would be a little surprised if they felt they needed a personal copy.

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