Book Review

Complex-Valued Neural Networks—A. Hirose (New York, NY: Springer-Verlag, 2006, Series on Studies in Computational Intelligence, pp. 176, ISBN-10: 3-540-33456-4, ISBN-13: 978-3-540-33456-9). *Reviewed by G. M. Georgiou*

This monograph is the first book to systematically treat the active and expanding field of complex-valued neural networks. It was originally published in Japanese. The only other volume that exists on the subject is a book whose chapters have been written by researchers in the field, and whose editor is the author of the book being reviewed.

Complex-valued neural networks simply stated are neural networks, which are defined in the complex domain. The complex domain has been a main staple in engineering and physics and it is only natural that it has attracted attention in the field of neural networks. Physical quantities are represented and manipulated in a most natural manner when one works in the complex domain. In particular, it is hard to imagine areas such as electromagnetics, electric circuits, signal processing, quantum mechanics, optics, and many others, without the realm of complex numbers. Amplitude and phase, which are so prevalent, are represented as a single quantity. Manipulation, be it through a Fourier transform or a matrix multiplication, is efficiently done in the complex domain.

What advantages do complex-valued neural networks offer? For one, they allow quantities to be represented and manipulated consistently both in the problem domain and in neural networks. This may appear as mere notational convenience, however it is not. Representation, i.e., encoding, of data is important. Consider, for example, the problem of having to classify data belonging to two classes that have the shape of two concentric bands. If magnitude information is included, classification is trivial. However, if one works only in Cartesian coordinates, classification becomes a substantially more difficult task. Another advantage is the ease with which periodicity can be represented with complex exponentials as opposed to real sinusoidal functions. Even when signals can be reconstructed completely from the real part of their complex representation, there may be an advantage in using their complex representation. One such example, which the author mentions, is the representation of real signals as analytic signals via the use of the Hilbert transform to create the imaginary part. Then, such signals can be conveniently processed with the Fourier transform. The book in its latter part provides detailed applications where complex-valued neural networks have been successfully applied.

The book is most useful for researchers who would like to enter the field of complex-valued neural networks, although it can serve as a textbook for advanced undergraduates and graduate students for an introductory course in neural networks. The mathematical background needed is some basic understanding of the complex domain, calculus, and some knowledge of linear algebra. To understand the applications in Part II, familiarity with frequency-domain analysis and electromagnetics is needed.

The book consists of 11 chapters and is divided in two parts. Part I consists of the chapters 1–4 and is titled "Basic Ideas and Fundamentals: Why are complex valued neural networks inevitable?" These chapters serve as an introduction to neural networks with their domain expanded to complex numbers.

1) Complex-valued neural networks fertilize electronics.
2) Neural networks: The characteristic viewpoints.
3) Complex-valued neural networks: Distinctive features.
4) Constructions and dynamics of neural networks.

In this part, the basics of neural networks are covered, such as activation functions, Hebbian rule, associative memory, function approximation, and self-organizing maps. A historical review of complex-valued neural networks, perhaps the most complete in print, is given. Of particular interest to researchers is section 3.3 "In what fields are CVNNs [complex-valued neural networks] effective?" where the author gives brief but convincing discussions of areas where CVNNs have been or can be applied. These areas include electromagnetic and optical waves, the electron wave, superconductors, quantum computation, sonic and ultrasonic waves, chaos and fractals, and others. This is a treasure trove for research ideas using CVNNs.

Part II titled "Applications: How wide are the application fields?" consists of chapters 5–11. Each of these chapters represents a research paper which describes an application of CVNNs to a problem. They are independent of each other. These results have been obtained in the author's laboratory at University of Tokyo, Tokyo, Japan, with the help of his students.

5) Land-surface classification with unevenness and reflectance taken into consideration.
6) Adaptive radar system to visualize antipersonnel plastic landmines.
7) Removal of phase singular points to create digital elevation map.
8) Lightwave associative memory that memorizes and recalls information depending on optical carrier frequency.
9) Adaptive optical phase equalizer.
10) Developmental learning with behavioral mode tuning by carrier-frequency modulation.
11) Pitch-asynchronous overlap-add waveform-concatenation speech synthesis by optimizing phase spectrum in frequency domain.

The first two applications (Chapters 5 and 6) use the complex version of self-organizing maps (C-SOM). In Chapter 7, phase unwrapping is used to create a "digital height map" from an image of Mount Fuji which has only phase information. A complex Markov random field cellular neural network is used to estimate reflection values, based on which height can be inferred. The network itself uses both amplitude and phase components. Chapters 9 describes an optical experiment, where a version of the complex-value Hebbian learning is used. Chapter 10 deals with developmental learning, i.e., learning successive similar tasks by fine tuning the neural network, which here is applied on a human-bicycle model. In Chapter 11, a complex neural network is employed in the frequency domain to adjust phases so that concatenation of speech elements yields acoustically acceptable sound.

It must be noted that some of the experiments involve actual experimental setups where physical measurements are taken as opposed to having simulations. These include Chapter 2, where Tokyo soil is used to cover plastic materials, and Chapters 8 and 9, where optical experiments are carried.

The book includes 123 bibliographic references and an index.

In summary, this is a milestone contribution in the field of complex neural networks, written by arguably its most well-known and prolific researcher. It can be profitably used not only by those who would like to be introduced to the field, but also by those who would like to contribute to it.

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