Guest Editorial
Special Issue on Complex- and Hypercomplex-Valued Neural Networks

COMPLEX-VALUED neural networks (CVNNs) exhibit very desirable characteristics in their learning, self-organizing, and processing dynamics, which makes them attractive for applications in various areas in science and technology. For example, they are perfectly suited to deal with complex amplitude, composed of amplitude and phase, which is one of the core concepts in physical systems dealing with electromagnetic, light, sonic/ultrasonic, and quantum waves. This, together with the widespread use of analytic signals and phasor representations, gives them a critical advantage in practical applications in diverse fields of engineering, where signals are routinely analyzed and processed in time/space, frequency, and phase domains. Besides, by convenience of representation, many big electromechanical engineering systems such as the electric power system are designed and analyzed in the complex domain. Then it is natural and timely to ask ourselves to which extent do CVNNs outperform standard approaches in various engineering fields. In addition, the bigger picture of CVNNs extends to quaternion and Clifford neural networks, as well as kernel and reservoir approaches; these underpin unique new directions in color-information treatment, robotics, control, and so forth.

This special issue was initiated by the Complex-Valued Neural-Network Task Force (CVNN-TF), founded by the IEEE Computational Intelligence Society (CIS) Neural Network Technical Committee (NNTC) in 2010 (`http://www.eis.t.u-tokyo.ac.jp/CVNN/`). The CVNN-TF has over 40 members and has been successful in promoting this area globally, through regular tutorials and special sessions in conferences within the IEEE CIS remit, and locally through various outreach and industry collaboration activities. IEEE TRANSACTIONS ON NEURAL NETWORKS AND LEARNING SYSTEMS has recognized the far-reaching theoretical and practical scope of this area and has organized this Special Issue entitled "*Complex- and Hypercomplex-Valued Neural Networks*." The special issue has attracted close to 40 manuscripts, and the submissions have been reviewed by over 120 reviewers, with 15 articles accepted. A brief introduction to the papers selected for this special issue is given below.

1) Theory-oriented papers include:

   Global Stability Criterion for Delayed Complex-Valued Recurrent Neural Networks deals with the stability problem in delayed complex-valued recurrent neural networks. By separating complex-valued networks into real and imaginary parts, forming an equivalent real-valued system, to construct appropriate Lyapunov functionals, the authors present a sufficient condition to ascertain the existence, uniqueness, and globally asymptotical stability of the equilibrium point of complex-valued systems.

   Further Investigate the Stability of Complex-Valued Recurrent Neural Networks With Time-Delays provides additional arguments and further evidence on two recent results on feasibility of complex-valued recurrent neural networks for neurodynamics applications. This work complements the previous works with new criteria for globally asymptotical stability of equilibria in recurrent CVNNs with time delays.

   Complex-Valued Recurrent Correlation Neural Networks generalizes the bipolar recurrent correlation neural networks of Chiueh and Goodman to memorize patterns of which components are on the complex unit circle. The author provides sufficient conditions for the retrieval of a memorized vector.

   The Field of Values of a Matrix and Neural Networks develops an algorithm and a generalization to find eigenpairs of a normal matrix using neural network techniques. The dynamics of the algorithm is illustrated as a recalling process on the complex plane. Shifting to assists in finding other eigenpairs is also discussed.

   Different Complex ZFs Leading to Different Complex ZNN Models for Time-Varying Complex Generalized Inverse Matrices introduces five different complex so-called Zhang functions (ZFs) to construct five different complex Zhang neural network (ZNN) models for online solutions of the time-varying complex generalized inverse matrices. The authors also discuss the link between the proposed complex ZNN models and the Getz–Marsden dynamic system in the complex domain.

2) Neural-network design papers are:

   MLMVN With Soft Margins Learning presents a modified error-correction learning rule for the multilayer neural network with multi-valued neurons (MLMVN). The modification is based on the soft margin technique, which leads to the minimization of the distance between a cluster center and the learning

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samples belonging to the cluster. The modified learning algorithm improves the generalization capability of MLMVN when solving classification problems.

Modified Multivalued Neuron With Periodic Tolerant Activation Function presents a revised model of multi-valued neuron with a periodic activation function based on the idea of unsharp boundaries. In this model, a fuzzy buffer is provided around a boundary between two distinct categories, allowing incorrect assignments with a membership degree value less than a threshold to be tolerated in the training phase. Genetic algorithms are applied to derive optimal values of the parameters involved in the model.

Threshold Complex-Valued Neural Associative Memory describes a class of threshold complex-valued neural associative memories for which the threshold is based on complex matrix decompositions, in order to equip this model with the capability of designing nonthreshold, threshold, non-Hermitian, and Hermitian networks. Experimental results show that constructed networks work efficiently in eliminating rotated patterns from spurious memories.

Principal Component Analysis With Complex Kernel: The Widely Linear Model formulates principal component analysis (PCA) in complex reproducing kernel Hilbert spaces by defining a general widely linear complex kernel PCA framework. The paper shows how to efficiently perform widely linear PCA in small sample sized problems.

A Metacognitive Complex-Valued Interval Type-2 Fuzzy Inference System presents a complex-valued interval type-2 neuro-fuzzy inference system and derives its meta-cognitive projection-based learning algorithm. As each sample is presented to the network, the meta-cognitive component monitors the hinge-loss error and class-specific knowledge potential of the current sample to efficiently decide what-to-learn and how-to-learn.

Complex-Valued B-Spline Neural Networks for Modeling and Inverting Hammerstein Systems describes a complex-valued B-spline neural network approach for efficient identification of complex-valued Hammerstein systems. A static complex-valued nonlinear function in the Hammerstein system is represented using the tensor product from two univariate B-spline neural networks. An accurate inversion of the system is also illustrated based on the estimated model.

3) Application papers include:

Fading Channel Prediction Based on Combination of Complex-Valued Neural Networks and Chirp Z-Transform proposes a highly accurate method to predict time-varying wireless communications channels by combining a multilayer complex-valued neural network with chirp Z-transform. In a series of simulations and experiments, the authors demonstrate that the channel prediction accuracy is better than using conventional prediction methods. The authors show that the crucial advantage of their approach is due to the way they deal with channel characteristics as complex entities.

Ultrawideband Direction-of-Arrival Estimation Using Complex-Valued Spatiotemporal Neural Networks presents a direction of arrival (DoA) estimation method using a complex-valued neural network for ultrawideband systems. The authors combine a complex-valued spatiotemporal neural network with power-inversion adaptive array scheme for null-steering DoA estimation. They demonstrate that the proposed method exhibits an estimation accuracy higher than that of the conventional multiple signal classification method, and that the spectrum floor is lower than that of real-valued neural networks.

Adaptive Dynamic Programming for a Class of Complex-Valued Nonlinear Systems develops an optimal control scheme based on adaptive dynamic programming to solve infinite-horizon optimal control problems of continuous-time complex-valued nonlinear systems.

On the Correction of Anomalous Phase Oscillation in Entanglement Witnesses Using Quantum Neural Networks deals with the entanglement witnesses in quantum systems. The authors propose a solution to the limits experienced when using quantum neural networks.

These papers deal with totally a broad range of topics, revealing the wide scope for applications and the profound essential nature of the world of the field of complex- and hypercomplex-valued neural networks. While the theory has been expanding and we are witnessing its unification, the applications of this methodology have been rapidly emerging. This special issue reflects the state-of-the-art, and our hope is to enthuse and encourage the academic and industrial researchers to lead further development in the forthcoming decades.

Finally, the guest editors would like to thank the reviewers for their dedication and thorough reviews, without their effort this special issue would not have been possible, and also wish to thank Editor-in-Chief, Prof. Derong Liu, for his administrative support. A big thank you also goes to the NNTC members for their continuous and most enthusiastic support to the activities of the CVNN Task Force.

Please enjoy!

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Dr. Hirose is a Senior Member of the Institute of Electronics, Information and Communication Engineers (IEICE) and a member of the Japanese Neural Network Society (JNNS). He served as the Editor-in-Chief of the *IEICE Transactions on Electronics*, an Associate Editor of journals such as the IEEE TRANSACTIONS ON NEURAL NETWORKS and the IEEE GEOSCIENCE AND REMOTE SENSING NEWSLETTER, the Chair of the Neurocomputing Technical Group in IEICE, and the General Chair of the 2013 Asia-Pacific Conference on Synthetic Aperture Radar in Tsukuba. He currently serves as a member of the IEEE Computational Intelligence Society Neural Networks Technical Committee, the Founding Chair of the Complex-Valued Neural Network Task Force in NNTC, the Governing Board Member of the Asia-Pacific Neural Network Assembly, the Co-Editor-in-Chief of the *Journal of Institute of Electronics, Information and Communication Engineers*, the Vice President of the IEICE Electronics Society, and the President of JNNS.

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Prof. Mandic is on the Board of Governors of the International Neural Networks Society, a Co-Chair of the Complex-Valued Neural Network Task Force in NNTC, and an Associate Editor of the IEEE SIGNAL PROCESSING MAGAZINE. He has held visiting positions with RIKEN, Kanazawa, Japan, and KU Leuven, Leuven, Belgium. He has received the President's Award for excellence in post-graduate supervision at Imperial College London, and awards for his papers and collaboration with the industry.