Guest Editorial

Learning and Repetitive Control

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The phrase "Intelligent Automation", the first part of the name of this journal, hints on the abstraction of Intelligence used in the field of Automation. Yet for the longest time, in reference to repetitive applications such as manufacturing, cyclic and vibrations control applications, the phrase would turn out to be an oxymoron. No matter how sophisticated the control system became including adaptive alteration of the control parameters, still no corrective action would be taken based on the information contained in previous cycles of a repetitive process. This was changed in 1984 with the advent of two papers [1, 5] which started to extend conventional ideas of Proportional-Derivative(PD) [1] and Integral(I) [5] controls to carry information from one repetition to the next. These papers initially addressed the problem of canceling periodic disturbances. This assumption in the field gave rise to what is known as **Learning Control** or recently as **Iterative Learning Control (ILC)**. Later, different attempts were made at handling the non-periodic signals which were deemed *manageable* under certain limitations [6]. This version of Learning control which handled some non-repetitive disturbances, given special characteristics, became known as **Repetitive Control** in the literature. Further improvements were made to take advantage of Adaptive Control ideas in the repetition domain [4]. Furthermore, ideas based on direct techniques such as Optimization Methods [2] were used. Other tools such as Neural Networks and Genetic Algorithms also found their way in the Learning and Repetitive Control field. The evolution of the Learning and Repetitive Control field is not very different from that of the conventional control field and has given rise to many contributions in the study of convergence and robustness of the controllers. This is especially important with Repetitive Control which tries to deal with taming non-repetitive disturbances present in any practical rendition of any repetitive system due to change of conditions, wear, etc. Most of the work in Learning and Repetitive Control tries to create a conceptual *discrete* time-line between any time point of a period with the corresponding time point one period away and hence a discretization is necessary which gives rise to a discrete-control scheme. Recently, some successful attempts have been made in treating continuous systems with a repetitive cycle in the Learning Control arena as connected with the more advanced adaptive approach. Continuous treatment of the simpler PD-type controller has been done in the past. [1]

This Collection

In this special issue, I am pleased to have been able to compile a series of papers from many of the pioneers of the Learning and Repetitive Control fields. This collection process started in 1997 and it has just been completed into an issue with presence from some of the best representative papers of the different aspects of the field discussed in the above introduction.

Learnability and Adaptability from the Viewpoint of Passivity Analysis
Arimoto and Naniwa

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The first author of this paper, Professor Arimoto is one of the original authors of the first two papers on Learning Control [1]. The paper presented in this issue treats the role of passivity of the input and output in Learning capabilities.

Design Issues on Robustness and Convergence of Iterative Learning Controller
Lee and Bien

Professor Bien has done a great deal of work on Iterative Learning Control. The paper in this issue treats robustness to the initial error and the convergence of a Learning Controller. The paper uses the PD-based Learning Control for these studies.

The Phenomenon of Apparent Convergence Followed by Divergence in Learning and Repetitive Control
Longman and Huang

Professor Longman, one of the authors of the first two major papers in the field [5] has had quite a long series of publications related to Learning and Repetitive Controls. The paper presented in this issue deals with an instability phenomenon which has been seen in experimental trials and gives rise to increases in the error after some number of iterations have elapsed. Initially, the Learning Controller may be converging, but after many iterations divergence occurs. Treatment methods are presented for stopping this type of divergence.

Handling Non-Periodic Disturbances in Repetitive Control Systems with Applications to Robot Manipulators
Tenney and Tomizuka

Professor Tomizuka has been working on treating special cases of non-repetitive disturbances in the past. This paper speaks about two techniques for reducing the effect of one-time non-repetitive disturbances on deeming the system unstable in future repetitions (iterations). It is a good example of Repetitive Control.

Direct Model Reference Learning and Repetitive Control
Lee, Longman and Phan

This paper uses the Model-Reference adaptive concept in creating a Learning Controller. This is in contrast with the Proportional-Derivative (PD) or Integral (I) controllers.

Direct Learning Neural Controller Tuned by Real Number Genetic Algorithm
Chbat and Li

This paper uses Neural Networks as well as Genetic Algorithms to address the Learning Control problem. It falls under an adaptive scheme since the Neural Network Learning Controller tries to learn the plant dynamics in its operation.

Updating Procedures for Iterative Learning Control in Hilbert Space
Avrachenkov, Beigi and Longman

This paper is a continuation of work which was presented originally in 1991 [2] and later extended in one of the earlier issues of this journal [3]. The paper presented in this issue extends Optimization-Based methods of Adaptive Control to continuous systems by formulating the Learning Control in Hilbert Space and presents a proof of convergence for Adaptive Learning Control of continuous systems.

References

[1] S. Arimoto, S. Kawamura, and F. Miyazaki, "Bettering operation of robots by learning", *Journal of Robotic Systems*, Vol. 1, 1984, pp. 123-140.

[2] Homayoon S.M. Beigi, C. James Li, and R.W. Longman, "Learning control by numerical optimization methods", Sensors, Control, and Quality Issues in Manufacturing, ASME, Atlanta, 1991, pp. 163-175.

[3] Homayoon S.M. Beigi, "Adaptive and Learning-Adaptive Control Techniques based on an Extension of the Generalized Secant Method," *Intelligent Automation and Soft Computing Journal*, Vol. 3, No. 2, 1997, pp. 171-184.

[4] C. James Li, Homayoon S.M. Beigi, Shengyi Li, Jiancheng Liang, "Nonlinear Piezo-Actuator Control by Learning Self-Tuning Regulator," *ASME Tr., J. of Dynamic Systems, Measurement, and Control*, Vol. 115, No.4, December 1993, pp. 720-723.

[5] R.H. Middleton, G.C. Goodwin, and R.W. Longman, "A method for improving the dynamic accuracy of a Robot performing a repetitive task", *the International Journal of Robotics Research*, Vol. 8, No. 2, October 1989, pp. 67-74. Also available as Elec. Engin. Tech. Rep. EE8546, University of New Castle, New Castle, Australia, 1985.

[6] M. Tomizuka, "Zero Phase Error Tracking Algorithm for Digital Control," *ASME Journal of Dynamic Systems, Measurement, and Control*, Vol. 109, March 1987.

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was born in Tehran, Iran in 1964. He received his Bachelors, Masters and Doctorate degrees from the Department of Mechanical Engineering at Columbia University in 1984, 1985 and 1990 respectively. His Doctoral thesis was on Learning Control and Neural Network Learning. He worked on lossless image compression at the Center for Telecommunication Research at Columbia University for 6 months after receiving his Doctorate degree and joined the handwriting recognition group at IBM T.J. Watson Research Center in New York in February of 1991 where he held the position of Research Staff Member until February of 2001 working on Handwriting, Signature, Speaker and Speech Recognition research problems and algorithm development in depth. At the present he is the Vice President and Chief Technology Officer of Internet Server Connections, Inc. which is headquartered White Plains, NY. At Internet Server Connections, he has worked on research projects dealing with extremely large and sparse optimization problems (in the R^{10^4} space) and networking issues. In addition, he holds a position as an Adjunct Associate Professor at the Electrical and Mechanical Engineering Departments of Columbia University, teaching Control, Speech and Handwriting Recognition. His Speech Course is also distributed in Video form via the Columbia Video Network. Homayoon Beigi has been the recipient of two best paper awards from the Institute of Electrical and Electronic Engineers (IEEE) for his work in Neural Network Learning. He has been an Associate Editor of the Intelligent Automation and Soft Computing Journal since its conception. Homayoon Beigi was also an Executive Committee Member of the Society for Technological Advancement in Developing Countries from 1991 to 1994. He is a Senior Member of the IEEE, a permanent reviewer for the IEEE Spectrum Magazine and has served as the Editor for the handwriting recognition chapter of the Berkeley Initiative in Soft Computing. Homayoon Beigi has published in the fields of Kinematics, Neural Networks, Optimization, Learning Control, Adaptive Control, Signal Processing, Image Compression, Statistical Language Modeling, Handwriting, Speaker, Speech, Music and Signature Recognition. He currently holds 4 US Patents in the above fields and has few pending patents applications.