

ITERATIVE LEARNING CONTROL FOR NONLINEAR SYSTEMS

by

S. GOPINATH

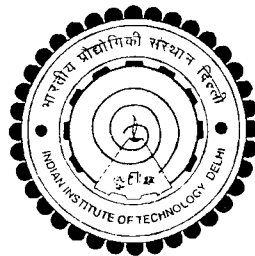
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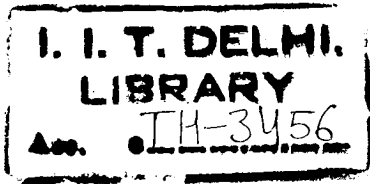
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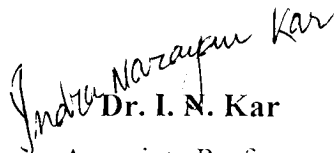


Certificate

This is to certify that the thesis entitled “**Iterative Learning Control for Nonlinear Systems**”, being submitted by **Mr. S. Gopinath** to the Department of Electrical Engineering, Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** is a record of bona-fide research work carried out by him under our supervision. In our opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree.

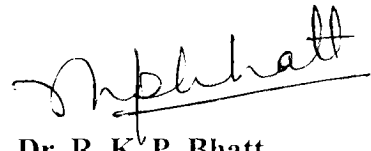
The results contained in this thesis have not been submitted either in part or in full to any other University or Institute for the award of any degree or diploma.

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To my parents,

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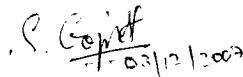
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Abstract

Learning control starts with a fundamental recognition that repeated practice is a common mode of human learning. Learning control is most suitable for operations where the same task is to be performed over and over again. Many industrial systems and machines perform their tasks which are repetitive in nature, for e.g., robots, steel mills, hard-disk drives and many more. These systems are required to carry out tasks with precision and high speeds subject to modeling variations and disturbances (both repetitive and non-repetitive). Iterative learning control (ILC) is a new domain in control system that motivates, whether mechanical robots can learn a prescribed ideal motion by themselves using information represented by the measured data gathered in the previous practice. In ILC, the necessary control input can be synthesized by repeated trials based on tracking errors.

In this thesis, two different types of series approximation based learning controller design methods are proposed for a class of nonlinear systems. They are wavelet series and Hermite series expansions. These series approximation approaches are used to approximate the desired and actual trajectories of the system into finite number of wavelet/Hermite coefficients. A learning controller is designed in wavelet/Hermite domain which forces the coefficients of the actual output approach to the corresponding coefficients of the desired trajectory, which are known constants. Equivalently, this achieves the tracking control problem in time domain. In wavelet series based approach, only the coefficients of basis functions of approximation subspace in wavelet transform are used for the updation of control. Thus the control input to the system is free from high

frequency components, which may correspond to the disturbances. Interesting characteristics such as reduced computation and easier implementation of orthonormal Hermite basis functions are exploited for the design of proposed Hermite series based learning controller. Convergence and stability analysis of the proposed wavelet & Hermite series based approaches ensure the convergence of coefficients of actual trajectory to the respective coefficients of desired trajectory. Numerical experimentation on robot systems show the ability of the proposed learning controller designed in wavelet/Hermite domain in the presence of system parameter uncertainties.

For each new desired trajectory task, the learning controller has to start its learning with zero initial input assumption. Instead of such zero initial input assumption, in this thesis the idea of using the past trajectory tracking experiences on the initial input selection for tracking a new trajectory tracking tasks has been explored. In this thesis, fuzzy modeling based experience inclusion approaches for ILC are proposed. Approximate fuzzy data model (AFDM) and Type-1 fuzzy logic system (FLS) based experience inclusion techniques have been developed for the purpose of appropriate initial input selection. Initial iteration error reduction and error convergence issues are proved for the proposed methods. Comparison studies with local learning technique show the efficacy of the proposed fuzzy rule based modeling approaches.

A 2-D Roesser's model for a class of learning controllers is established, which reveals the connections between ILC systems and 2-D system theory. After proper transformation of ILC system into a 2-D system model, certain fundamental results from the state feedback stabilization of 2-D systems are utilized for the design of ILC. A

simple design procedure is proposed for the design of 2-D system theory based ILC algorithm. The design of state feedback controller for the 2-D system is simplified into stabilization problem of two reduced order 1-D systems. Proposed methodology considerably reduces the computational complexity in comparison with existing approaches. Proposed ILC design approach is tested numerically for an injection molding process control problem. Results show the robust performance of the proposed 2-D system theory based ILC over the perturbations on system parameters and on initial conditions.

A close relative of ILC is repetitive control (RC). In learning control, the system is designed to return to the same initial condition before each new execution of the task, as in the case of a robot performing a task on each item that arrives one by one on an assembly line. Repetitive control, on the other hand, applies to the situation where the desired trajectory to be tracked is a periodic function of time, and there is no resetting between periods, e.g. high speed cam follower systems. Due to the spillover of the cam systems the same initial condition assumption during each cam cycle is practically not possible. Results of proposed wavelet series and 2-D system theory based ILC approaches are extended for the RC design problems. Proposed RC design approaches are applied for the elimination of residual vibrations in high-speed cam follower systems.

Contents

	Page No.
Abstract	vi
List of Figures	xiii
List of Tables	xviii
List of Principal Symbols and Abbreviations	xix
1. Introduction	1
1.1 Iterative Learning Control- A brief overview	2
1.2 Motivation	3
1.3 Literature Survey	6
1.4 Organization of Thesis	15
2 Wavelet Series Based Iterative Learning Control	18
2.1 Introduction	18
2.2 Problem Statement	19
2.3 Robot Dynamics Including Actuator Model	20
2.4 Wavelet Series based Learning Controller	22
2.4.1 Multiresolution Analysis (MRA)	23
2.4.2 Wavelet Series Approximation	24
2.4.3 Learning Controller Design	25
2.4.4 Convergence Analysis	30
2.4.5 Implementation Procedure	32
2.5 Numerical Experimentation	33
2.5.1 Trajectory Tracking Problem of Robot Manipulator	34

2.5.2	Kinematic Path Tracking Problem of Mobile Robot	42
2.5.3	Analysis and Discussion	49
2.6	Conclusions	50
3	Hermite Series Based Iterative Learning Control	51
3.1	Introduction	51
3.2	Problem Statement	52
3.2.1	Robot Manipulator Dynamics Including Actuator Model	53
3.3	Hermite Series Based Learning Controller	54
3.3.1	Hermite Series Expansion	54
3.3.2	Properties of Hermite Functions	57
3.3.3	Learning Controller Design	58
3.4	Convergence Analysis	61
3.5	Implementation Procedure	63
3.6	Numerical Experimentation	64
3.6.1	Trajectory Tracking Problem of SDOF System	65
3.6.2	Trajectory Tracking Problem of 2-DOF System	70
3.7	Conclusions	76
4	Experience Inclusion in Iterative Learning Controllers	
	- Fuzzy Modeling Approaches	77
4.1	Introduction	77
4.2	Problem Formulation	78
4.3	Experience Inclusion Techniques Using Local Weighted Learning	79
4.3.1	Selection of Initial Control Input	81
4.4	Fuzzy Modeling Based Experience Inclusion	82

4.4.1	AFDM Methodology	83
4.4.1.1	Rule-base Formulation for AFDM	83
4.4.1.2	Selection of Initial Control Input by AFDM	84
4.4.2	Type-1 Fuzzy Logic System (FLS) Based Approach	86
4.4.2.1	Rule-base Formulation and Initial Input Selection by Type-1 FLS	86
4.4.2.2	Designing Type-1 FLS using Back-Propagation Method	87
4.5	Initial Iteration Error Reduction and Convergence Issues	89
4.6	Numerical Experimentation	94
4.6.1	Physical Plant	94
4.6.2	Formulation of Fuzzy Rule-base from Experience Database	95
4.6.3	Implementation and Error Reduction Issues	97
4.7	Conclusions	107
5	Two-Dimensional (2-D) System Theory Based Iterative Learning Control	108
5.1	Introduction	108
5.2	System Description and Problem Statement	110
5.3	2-D Representation of ILC Process	113
5.4	State Feedback Stabilization of 2-D Systems	115
5.4.1	Stability of 2-D systems	116
5.4.2	Design for Gain \bar{K}_1	118
5.4.3	Design for Gain \bar{K}_2	118

5.5	Numerical Experimentation	120
5.5.1	Plant Description	121
5.5.2	Results and Discussion	122
5.6	Conclusions	129
6	Repetitive Control using Wavelet Series and 2-D System Theory	130
6.1	Introduction	130
6.2	Wavelet Series Based Repetitive Control	132
6.2.1	Numerical Experimentation	133
6.2.2	Results and Discussion	138
6.3	2-D System Theory based RC Design	142
6.3.1	Numerical Experimentation	145
6.4	Conclusions	149
7	Conclusions and Future Scope of Work	150
7.1	Summary and Conclusions	150
7.2	Future Scope of Work	154
	References	156
	Appendices	168