Iterative Learning Control: Brief Survey and Categorization

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***Abstract*—In this paper, the iterative learning control (ILC) literature published between 1998 and 2004 is categorized and discussed, extending the earlier reviews presented by two of the authors. The papers includes a general introduction to ILC and a technical description of the methodology. The selected results are reviewed, and the ILC literature is categorized into subcategories within the broader division of application-focused and theory-focused results.**

***Index Terms*—Categorization, iterative learning control (ILC), literature review.**

I. Introduction

ITERATIVE learning control (ILC) is an effective control tool for improving the transient response and tracking performance of uncertain dynamic systems that operate repetitively. Systems typically treated under the ILC framework are repetitively operated dynamic systems, such as a robotic manipulator in a manufacturing environment or a chemical reactor in a batch processing application. The ILC notion can also be extended to include periodically disturbed or periodically driven dynamic systems, where the periodicity could be time-, state-, or trajectory-dependent. More generally, the key idea of ILC can be viewed as a multipass process. Historically, the first novel idea related to a multipass control strategy can be traced back to [115], published in 1974, though the stability analysis was restricted to classical control concepts and did not explicitly cover the ILC approach. Interestingly, the essential idea of iterative learning was captured even before 1970, not in the archival literature, but in a U.S. patent, as explained in [65].

The purpose of this paper is to provide a summary and review of the recent trends in ILC research from both the application point of view and the theoretical point of view. We focus on the literature published between 1998 and 2004, logically extending three previous surveys presented by two of the authors of the papers [62], [275], [282]. Section I continues with a general introduction to ILC and a technical description of the methodology. In Section II, we summarize the survey methodology that we used and present selected results from recent literature. Section III is the main part of the paper, where we separate the literature into application-focused results and theory-focused results, giving detailed subclassifications of each of these broader categories. Section IV presents some concluding remarks.

Manuscript received July 24, 2005; revised May 4, 2006, August 7, 2006, and November 29, 2006. This paper was recommended by Associate Editor P. Horacek.

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Digital Object Identifier 10.1109/TSMCC.2007.905759

A. What Is ILC?

Control systems have played an increasingly important role in the development and advancement of modern civilization and technology. Control problems arise in practically all engineering areas and have been studied by both engineers and mathematicians. In industry, control systems are found in numerous applications, including quality control of manufactured systems, automation, network systems, machine tool control, space engineering, military, computer science, transportation systems, robotics, social systems, economic systems, and biological/medical engineering, among others. Mathematically, control engineering includes modeling, analysis, and design of control systems. The key feature of control engineering is the use of feedback signals for performance improvement of a controlled system. The branches of current control theories are broad and include classical control, robust control, adaptive control, optimal control, nonlinear control, neural network, fuzzy logic, and intelligent control.

ILC is a relatively recent but well-established area of study in control theory. ILC, which can be categorized as an intelligent control methodology,[1] is an approach for improving the transient performance of systems that operate repetitively over a fixed time interval. Although control theory provides numerous design tools for improving the response of a dynamic system, it is not always possible to achieve desired performance requirements, due to the presence of unmodeled dynamics or parametric uncertainties that are exhibited during actual system operation or to the lack of suitable design techniques [274]. Thus, it is not easy to achieve perfect tracking using traditional control theories. ILC is a design tool that can be used to overcome the shortcomings of traditional controller design, especially for obtaining a desired transient response, for the special case when the system of interest operates repetitively. For such systems, ILC can often be used to achieve perfect tracking, even when the model is uncertain or unknown and we have no information about the system structure and nonlinearity.

Various definitions of ILC have been given in the literature. Some of them are quoted here.

1) The learning control concept stands for the repeatability of operating a given objective system and the possibility

[1] From "Defining intelligent control, report of the task force on Intelligent Control," IEEE Control Systems Society, Panos Antsaklis, Chair, December 1993: ". . . intelligent control uses conventional control methods to solve lower level control problems . . . conventional control is included in the area of intelligent control. Intelligent control attempts to build upon and enhance the conventional control methodologies to solve new challenging control problems. . . ."

of improving the control input on the basis of previous actual operation data (Arimoto *et al.* [27]).
2) It is a recursive online control method that relies on less calculation and requires less *a priori* knowledge about the system dynamics. The idea is to apply a simple algorithm repetitively to an unknown plant, until perfect tracking is achieved (Bien and Huh [37]).
3) ILC is an approach to improving the transient response performance of the system that operates repetitively over a fixed time interval (Moore [274]).
4) ILC considers systems that repetitively perform the same task with a view to sequentially improving accuracy (Amann *et al.* [9]).
5) ILC is to utilize the system repetitions as experience to improve the system control performance even under incomplete knowledge of the system to be controlled (Chen and Wen [60]).
6) The controller that learns to produce zero tracking error during repetitions of a command, or learns to eliminate the effects of a repeating disturbance on a control system output (Phan *et al.* [332]).
7) The main idea behind ILC is to iteratively find an input sequence such that the output of the system is as close as possible to a desired output. Although ILC is directly associated with control, it is important to note that the end result is that the system has been inverted (Markusson [266]).
8) We learned that ILC is about enhancing a system's performance by means of repetition, but we did not learn how it is done. This brings us to the core activity in ILC research, which is the construction and subsequent analysis of algorithms (Verwoerd [433]).

All definitions about ILC have their own emphases. However, a common emphasis of these definitions is the idea of "repetition." Learning through a *predetermined* hardware repetition is the key idea of ILC. Hardware repetition is a physical layer on the uniformly distributed time axis for providing experience to the mental layer of ILC. "Predetermined" means that the ILC system requires some postulates that define the learning environment of a control algorithm. A person learns his/her living environment by experience where the physical layer is their daily activity and the mental layer is the memory of strongly perceived events that are closely related to his/her interest. These strongly perceived events of the past provide knowledge to a human being that can be used for their current activity. In ILC, the current activity is a control force and the past experience is stored as data. A difference between human learning and machinery learning is in the "predetermined" aspect. For a human being, knowledge by learning could be based on similarity and impression, whereas in a machine, the initial setup, fixed time point, uniform sampling, repetitive desired trajectory, etc. are predetermined, which may be used to determine the future actions of the hardware machine.

Following the definitions earlier, we can say that ILC is an approach to improve the transient response performance of an unknown/uncertain hardware system that operates repetitively over a fixed time interval by using the previous actual operation data to compensate for uncertainty. The key question of ILC is how to eliminate the uncertainty by using past performance information on the current trial. If the system uncertainty and external disturbances are predetermined on the uniformly distributed repetitive time axis, then finding an "inverse" of these predetermined effects can be thought of as the main objective of ILC.

B. Technical Overview of ILC

In this section, we summarize basic ILC algorithms, both continuous time and discrete time, and their convergence properties. For discrete-time ILC, we focus especially on the so-called supervector framework.

1) Continuous-Time Ilc: As shown from the categorization in Section III, the scope of ILC research is so wide that it is nearly impossible to introduce all the branches of ILC. In this section, the basic ideas of ILC algorithms are briefly reviewed. Let us consider the following linear continuous-time system:

$$\dot{x}_k(t) = Ax_k(t) + Bu_k(t) \tag{1}$$

$$y_k(t) = Cx_k(t). \tag{2}$$

The control task is to servo the output y_k to track the desired output y_d on a fixed interval $t \in [0, T]$ as the iteration k increases. In classical ILC, the following basic postulates are required, although in recent ILC research some of these postulations have been relaxed.

1) Every trial (pass, cycle, batch, iteration, repetition) ends in a fixed time of duration.
2) Repetition of the initial setting is satisfied. That is, the initial state $x_k(0)$ of the objective system can be set to the same point at the beginning of each iteration.
3) Invariance of the system dynamics is ensured throughout the repetition.
4) Output $y_k(t)$ is measured in a deterministic way.
5) The system dynamics are deterministic.

Under these assumptions, if the system has relative degree one or less, an iterative learning control scheme of the "Arimoto-type" [25], [26], given by

$$u_{k+1} = u_k + \Gamma\dot{e}_k \tag{3}$$

where $e_k(t) = y_d(t) - y_k(t)$, and Γ is a diagonal learning gain matrix, ensures that

$$\lim_{k\to\infty} y_k(t) \to y_d(t)$$

for all $t \in [0, T]$, if

$$\|I - CB\Gamma\|_i < 1 \tag{4}$$

where $\|\|_i$ is an operator norm and $i \in \{1, 2, \ldots, \infty\}$. Notice that the basic formula for selecting the learning gain given in (4) does not require information about the system matrix A, which implies that ILC can be effective for model-uncertain systems (though some knowledge of the system structure, such as its relative degree, is needed). This is a key characteristic of ILC.

Starting from the classical Arimoto-type ILC algorithm, we can develop a number of more general expressions. For instance, a "PID-like" update law can be given as [274]

$$u_{k+1} = u_k + \Phi e_k + \Gamma\dot{e}_k + \Psi\int e_k \mathrm{d}t \tag{5}$$

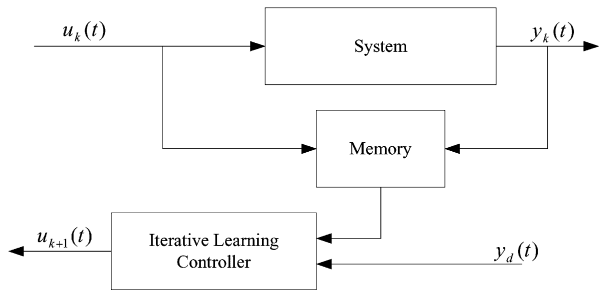

Fig. 1. Basic ILC configuration.

where Φ, Γ, and Ψ are learning gain matrices. A higher order ILC (HOILC)—meaning information from more than one previous trial is used in the ILC algorithm—PID-like update rule [60] can be formulated as

$$u_{k+1} = \sum_{k=1}^{N} (I - \Lambda) P_k u_k + \Lambda u_o + \sum_{k=1}^{N} \left(\Phi_k e_{i-k+1} + \Gamma_k \dot{e}_{i-k+1} + \Psi_k \int e_{i-k+1} \mathrm{dt} \right). \quad (6)$$

If $\sum_{k=1}^{N} P_k = I$, then by properly choosing the learning gain matrices, we can ensure that e_k converges to zero asymptotically [60]. Similarly, a time-varying P-type (meaning no derivative and integral effects) version of the ILC update rule given in (5) can be written as

$$u_{k+1}(t) = u_k(t) + \Gamma_k(t)(y_d(t) - y_k(t)) \quad (7)$$

where $\Gamma_k(t)$ is the proportional learning gain matrix that is now time varying. In this first-order ILC algorithm, by properly choosing the learning gain matrix $\Gamma_k(t)$, the ILC process will converge to zero steady-state error for systems of relative degree zero. Similar results can be developed for systems of relative degree one or higher. In this simple ILC algorithm, the key feature of ILC is to make use of information from the most recent past trial for the current update. Thus, it is also natural to derive time-varying HOILC update rules such as

$$u_{k+1}(t) = u_k(t) + \sum_{i=k}^{i=k-l} \Gamma_i(t)(y_d(t) - y_i(t)) \quad (8)$$

or

$$u_{k+1}(t) = \sum_{i=k}^{i=k-l} \Lambda_i(t) u_i(t) + \sum_{i=k}^{i=k-l} \Gamma_i(t)(y_d(t) - y_i(t)) \quad (9)$$

which uses not only the most recent previous control input/transient error information, but all of the previous control inputs/transient error information. These algorithms highlight the perspective that ILC is "a control law that uses all available past information for the performance improvement of a periodic system." This idea is depicted in block diagram form in Fig. 1, which shows the next trial's control input to be calculated from the previous trial's control input and transient error. In this figure, including more than one previous trial is accomplished by incorporating trial-to-trial dynamics (e.g., memory) in the block labeled "Iterative Learning Controller."

2) Discrete-Time ILC: So far, we have considered continuous-time ILC algorithms. However, since microprocessor-based systems are widely used in actual applications, it is practically desirable to use a discrete-time or sampled-data formulation. To this end, consider the discrete-time state-space model given as

$$x_k(t+1) = Ax_k(t) + Bu_k(t) \quad (10)$$

$$y_k(t) = Cx_k(t). \quad (11)$$

We suppose that system operates on a finite horizon given by $t \in [0, N]$ where t is an integer and that the system has relative degree m. Thus, each iteration domain consists of a finite number of discrete-time points, which can be used via lifting to form the following so-called "supervectors":

$$U_k = (u_k(0), u_k(1), \ldots, u_k(N-1)) \quad (12)$$

$$Y_k = (y_k(m), y_k(m+1), \ldots, y_k(N-1+m)) \quad (13)$$

$$Y_d = (y_d(m), y_d(m+1), \ldots, y_d(N-1+m)) \quad (14)$$

$$E_k = Y_d - Y_k = (E_k(m), E_k(m+1), \ldots, E_k(N-1+m)). \quad (15)$$

With these definitions, the linear plant can be described by $Y_k = HU_k$, where H is a matrix of rank N whose elements are Markov parameters of the plant $G(z)$

$$H = \begin{bmatrix} h_m & 0 & 0 & \ldots & 0 \\ h_{m+1} & h_m & 0 & \ldots & 0 \\ h_{m+2} & h_{m+1} & h_m & \ldots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ h_{m+N-1} & h_{m+N-2} & h_{m+N-3} & \ldots & h_m \end{bmatrix}. \quad (16)$$

In the literature, the supervector framework has been generalized to systems given by

$$x_k(t+1) = (A + \Delta A)(t) x_k(t) + (B + \Delta B)(t) u_k(t) + v(k,t) \quad (17)$$

$$y_k(t) = (C + \Delta C)(t) x_k(t) + w(k,t) \quad (18)$$

where now A, B, and C are time varying and ΔA, ΔB, and ΔC are model uncertainties, also time varying, but possibly characterized in the frequency domain or via interval mathematics, and $v(k,t)$ and $w(k,t)$ are time- and iteration-dependent process and measurement noises, respectively. In this case, by defining suitable supervectors representing the noise and disturbance signals, the system can be represented by

$$Y_k = (H + \Delta H) U_k + D_k \quad (19)$$

where the "plant" H is still lower triangular but no longer Toeplitz, D_k represents the collective effects of $v(k,t)$ and $w(k,t)$, and ΔH captures the uncertainty in the plant. Finally, we note that even more generally, for discrete-time multipass processes, we may allow the plant and the plant uncertainty to vary from trial to trial, resulting in a lifted model given by

$$Y_k = (H_k + \Delta H_k) U_k + D_k. \quad (20)$$

As discussed in [276], this formulation effectively transforms a 2-D problem into a multivariable 1-D problem.

Now consider the update algorithm in the supervector framework. A typical ILC update scheme for a plant with relative degree one, such as

$$u_{k+1}(t) = u_k(t) + \Gamma(q)e_k(t+1) \tag{21}$$

where $\Gamma(q)$ denotes a linear time-invariant filter using the standard abuse of notation, which would be expressed in the supervector notation as

$$U_{k+1} = U_k + LE_k. \tag{22}$$

The learning gain matrix L could be fully populated in the general case, corresponding to a time-variant noncausal learning operator or could have various forms of structure imposed, such as lower- or upper-triangular Toepliz, in the cases of completely causal or completely noncausal learning operators, respectively, or band-diagonal, corresponding to finite-impulse response (FIR) averaging operators (causal and noncausal), etc.

We may further consider HOILC in the supervector framework. Suppose our discrete plant has transfer function $G(z) = C(zI - A)^{-1}B$. It is assumed that $t \in [0, N]$. Without loss of generality, we take $m = 1$ and $CB \neq 0$. An earlier version of the following HOILC update rule was first introduced in [276] as

$$\begin{aligned} U_{k+1} = &-D_n U_k - D_{n-1}U_{k-1} - \cdots - D_0 U_{k-n} \\ &+ N_{n+1}E_{k+1} + N_n E_k + \cdots + N_1 E_{k-n+1} + N_0 E_{k-n} \end{aligned} \tag{23}$$

where k denotes the iteration trial; D_i are fixed learning gain matrices associated with the previous control input vectors; N_i are fixed learning gain matrices associated with the previous error vectors; and n is the number of the past trials used for the current control update (if $n = 0$, we have first-order ILC, and if $n \geq 1$, we have HOILC). This update equation expands on the results of [276] by the inclusion of the term $N_{n+1}E_{k+1}$. In the literature, this term is called "current-cycle feedback" (also called "current-iteration feedback" or CITE) and accounts for the action of a typical feedback controller that would be used even in the absence of ILC. We note that from the perspective of a design problem, the CITE gain N_{n+1} must be causal (i.e., lower triangular), while all the other matrices in (23) may be fully populated as they act on information from the past.

3) Ilc Convergence: Whether considering continuous-time or discrete-time ILC, the key focus in ILC literature has been the design of the ILC update algorithm and then the subsequent analysis of the convergence properties of the algorithm. Because the time-axis in an ILC problem is finite, ILC convergence refers to stability along the iteration axis. There are two convergence concepts to consider: asymptotic stability (AS) and monotonic convergence (MC). The former is concerned with whether an ILC algorithm converges as the number of iterations goes to infinity. The latter is concerned with the error getting smaller and smaller (in the sense of some norm) from iteration to iteration.

To illustrate the difference between AS and MC for first-order discrete-time ILC, consider the Arimoto-type update (22) where $L = \mathrm{diag}(\gamma)$. If the system is characterized by the matrix H and the first Markov parameters is h_1, then the (necessary and sufficient) condition for AS is $|1 - \gamma h_1| < 1$, whereas the (sufficient) condition for MC is $\|I - HL\|_i < 1$, a stronger condition to achieve, but one that ensures that the error gets smaller on each trial.

To discuss convergence for HOILC, it is helpful to introduce a shift operator w with the property that

$$w^{-1}u_k(t) = u_{k-1}(t).$$

This is just the standard z-transform, renamed to reflect the fact that it is operating from trial to trial, with time t fixed, as opposed to the standard z-transform operator, which operates from time step-to-time step, with k fixed. Thus, we may write $Y_k = HU_k$ as $Y_k(w) = HU_k(w)$. This represents the nominal plant. With this notation, taking the w-transform of both sides of the HOILC equation (23) with $N_{n+1} = 0$ (i.e., no CITE) and combining terms gives

$$D_c(w)U(w) = N_c(w)E(w)$$

where

$$\begin{aligned} D_c(w) &= Iw^{n+1} + D_n w^n + \cdots + D_1 w + D_0 \\ N_c(w) &= N_n w^n + N_{n-1}w^{n-1} + \cdots + N_1 w + N_0 \end{aligned}$$

which can also be written in a matrix fraction as $U(w) = C(w)E(w)$ where

$$C(w) = D_c^{-1}(w)N_c(w).$$

Combining this controller representation with the plant, the repetition-domain closed-loop dynamics becomes

$$G_{\mathrm{cl}}(w) = H[D_c(w) + N_c(w)H]^{-1}N_c(w).$$

Thus, we can say that the system is AS if G_{cl} is stable. Standard techniques from linear multiple-input multiple-output (MIMO) controller design can be used to design the learning matrices in (23) to ensure AS. However, the study of MC is still an open question for HOILC.

II. From 1998 to 2004: an Overview

A. Methodology of Literature Search

There have been a number of previous reviews and surveys of ILC. Of particular note is the two part ILC overview and critical analysis papers [454], [455] by Xu, which includes references through 2002. Part I [454] gives a thorough analysis of contraction-mapping-based ILC while Part II [455] describes the use of energy functions for ILC and relates ILC to adaptive control. In previous publications, two of the authors of the present paper have presented major ILC surveys in 1992 [282, Sec. 2], 1997 [62, Ch. 1], and 1999 [275, Ch. 4.4]. Detailed explanations about ILC research before 1990 were provided in [282, Sec. 2]. The first part of [282, Sec. 2] introduced Japanese researchers who suggested LTI Arimoto-type gains (see below), PID-type gains, and gradient method-based optimization algorithms for ILC. In the latter part of [282, Sec. 2], literature dealing with nonlinear ILC, robustness of ILC, adaptive schemes in ILC, the optimal control approach to ILC, and neural-network-based ILC was introduced. An earlier classification of ILC works was given in [62, Ch. 1], and a wider ILC classification was given in [275, Ch. 4.4]. Note that in [275], the literature published before

TABLE I
ILC-RELATED PUBLICATIONS FROM WEB OF SCIENCE AND IEEE XPLORE

Search options	From "Web of Science"	From "IEEE Conference"	Total
Iterative + Learning	793	1117	1910
Learning + Control	12739	7521	20260
Iterative + Learning + Control	367	510	877
Iterative Learning Control	241	269	510
Repetitive Control	150	159	309

TABLE II
MISCELLANEOUS ILC-RELATED PUBLICATIONS FROM 1988 TO 2004

IFAC 1999 WC	IFAC 2002 WC	2000 ASCC	2002 ASCC	AJC	Others	Total
12	19	20	11	14	7	83

1997 was classified into two main categories: theoretical works and applications. We have retained this approach in this paper. Also note that a total number of 256 publications were covered in [275], which were obtained by searching on the keywords ("Control" AND "Learning" AND "Iterative"). Though it is out of the time range of the present survey, we note a recent survey that appeared in 2006, which provides a detailed technical survey on ILC algorithms along with new results on the design of the so-called Q-filter [42].

The present survey began with a search on the "Web of Science"[2] and "IEEE Xplore"[3] sites conducted on January 4, 2005. Table I shows the search results. As shown in this table, from the keywords ("Control" AND "Learning" AND "Iterative"), we have a total number of 877 publications. Given that there were 256 citations in [275], we can argue that since 1998 there have been approximately 600 publications related to ILC. A more broad but reliable broader search was also carried out using the keyword combinations ("Iterative" AND "Learning") and ("Learning" AND "Control"), from which we have 1910 and 20 260 publications, respectively. Thus, connected to the word "Learning," a great deal of literature has been published. We also searched under a related topic using the keywords "Repetitive Control," from which we obtained 309 publications. Given these large number of publications, in this paper, our review is restricted to the literature obtained by searching under the exact phrase "Iterative Learning Control," from which 510 different publications were found. However, for a reliable survey, we also decided to include papers from selected conferences and journals that could not be searched in the Web of Science and IEEE Xplore databases. Specifically, we also considered papers in the 1999 and 2002 World Congresses (WC) of the International Federation of Automatic Control (IFAC), the 2000 and 2002 Asian Control Conferences (ASCC), the 2001 European Control Conference (ECC), the 7th Mechatronics Conference, the *Asian Journal of Control* (AJC), and several other miscellaneous conferences where ILC papers appeared (see Table II). Thus, this paper covers IEEE conference and journal papers, papers in international journals listed in SCIE, IFAC conference papers, and ASCC papers.

Fig. 2 gives a graphical depiction of the number of ILC publications since 1990 in international conference proceedings and journals. As shown in Fig. 2, the number of publications increased steadily up to 2002, but then seems to have tapered off. We do not have an explanation for this effect, though the large number of conference publications in 2002 may be due to the IFAC WC. It is also interesting to note Table III, which shows the regional distribution of the authors of the literature, which was published in IEEE conference proceedings and SCIE journals (from the Web of Science database).

[2]http://isi01.isiknowledge.com/portal.cgi/wos
[3]http://ieeexplore.ieee.org

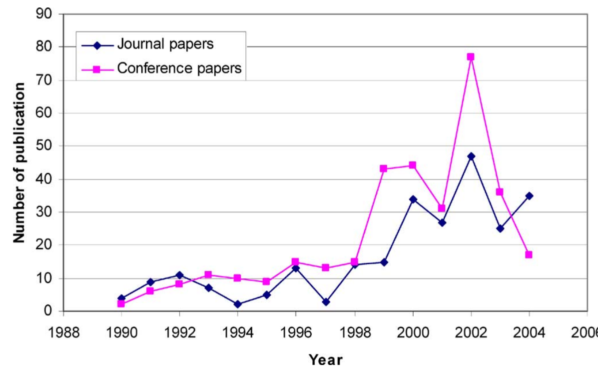

Fig. 2. Number of ILC-related publications in conference proceedings and journals.

TABLE III
REGIONAL DISTRIBUTION OF AUTHORS OF IEEE CONFERENCE PAPERS AND SCI JOURNAL PAPERS

Region	From "Web of Science"	From "IEEE Conference"	Total
China	18	55	73
Korea	60	15	75
Singapore	68	39	107
Japan	32	30	62
Taiwan	9	5	14
UK	47	29	76
Europe	42	30	72
USA	63	39	99
Canada	11	8	19
Other areas	6	6	12

Table I and II and Fig. 2 give gross statistics about the number of ILC publications. In Sections II-B and III, we expand on these tables by reviewing selected results from the recent literature and then separating the papers into detailed subclassifications, respectively.

B. From 1998 To 2004: Brief Comments on Selected Literature

The first ILC monograph [274] was published in 1993. After 1998, there were an editorial publication [38] in 1998; three special issues (a special issue of the *International Journal of Control* [285] in 2000), (a special issue of the *Asian Journal of Control* in 2002), and (a special issue of the *Intelligent Automation and Soft Computing: Learning and Repetitive Control* [115]); and two more ILC monographs [60], [480] in 1999 and in 2003, respectively. The outcome of the 2nd Asian Control conference held in Seoul, Korea, in July, 1997, is presented in [38]; and [285] is the outcome of the 1998 IEEE Conference on Decision and Control held in Tampa, FL. It is useful to read [38, Ch. 1, 2]. In Chapter 1, as a conclusion, Arimoto argued that the P-type update rule may be more natural than D-type ILC. In Chapter 2, Xu and Bien described several key issues in ILC research and commented on the limitations of ILC applications. Their discussions were given in three different categories: tasks, a connectivity of ILC to other control theories, and ILC issues in a future research direction. In [60], the nonlinear HOILC was developed to address robust ILC stability, and in [480], nonlinear ILC, mostly based on the idea of a composite-energy function, was described.

We also note that since 1998, at least 18 different Ph.D. dissertations can be found, as shown in Table IV, which was developed from a search on the "Digital Dissertations" Website[4] combined with information suggested by an anonymous reviewer [103], [131], [152], [176], [200], [246], [254], [261], [266], [304], [306], [336], [385], [433], [446], [499], [502], [513].

In the following sections, we will briefly review the special issue, vol. 73, no. 10, of the *International Journal of Control* (IJC) [285] and the Ph.D. dissertations. The IJC special issue includes well-refined ILC topics while the Ph.D. dissertations represent interesting ILC applications and some important theoretical developments.

1) IJC Special Issue, vol. 73, no. 10, 2000: The IJC special issue contained 15 articles that were based on presentations made at the *Iterative Learning Control Workshop and Roundtable*, a two-day meeting of 28 ILC researchers preceding the 1998 IEEE Conference on Decision and Control. Papers in the special issue included theoretical contributions related to the authors' expertise in conventional control theories, as well as applications ranging from semiconductors to robots to process control.

In [28], Arimoto presented ideas on the equivalence between "learnability," "output-dissipativity," and "strictly positive realness." Based on [28, Th. 1–4], it is possible to check if there exists an ILC controller to give input–output l_2 stability of the controlled system. In the general case when $D = 0$, learnability can be checked by investigating if there exist two positive-definite symmetric matrices X and Q such that

$$A^T X + XA = -Q \quad XB = C^T. \tag{24}$$

In [130], a linear quadratic ILC scheme was modified so as to reduce the dimension of the supervectors in calculating an optimal control at each trial and to estimate an unknown system model based on conjugate basis vectors. French and Rogers [126] provided an adaptive ILC with a calculated cost for l_p-bounded disturbances. This paper also discussed how to handle the robustness issue in the adaptive control framework. Owens and Munde [312] also provided a new adaptive approach for ILC systems. They included the current error feedback into an adaptive control law to exploit the fact that the most recent error data reflects the current performance most closely. Also, by including the feedback signal, they could stabilize an unstable plant during each trial. Xu *et al.* suggested a robust learning controller (RLC) in [484] for robotic manipulators to compensate for state-independent periodic uncertainties and to suppress nonperiodic system uncertainties. As commented in the same paper, the results of [484] can be applied to various periodically disturbed systems and to uncertain dynamic systems (see Section III-B8). In [326], the initial- state-error problem was handled. In [187], Hillenbrand and Pandit provided a design scheme for two-norm convergence using the idea of reduced sampling rate. Anticipatory ILC was suggested by Wang at the ILC Round Table Workshop held at the 1998 IEEE CDC and published in [437] and [438], whereby an ILC update rule was given by

$$u_{i+1}(t) = u_i(t) + L(\cdot)[y_d(t+\triangle) - y_i(t+\triangle)] \tag{25}$$

with a saturation condition also included on the input. Notice that the update rule is different from D-type or P-type (also compare this with [8]). In [79], Chien suggested an ILC design method based on fuzzy control for sampled-data systems. In [357], a state observer and a disturbance model were used to the learning controller. Longman gave a valuable discussion in [259], providing several important guidelines for the actual design of ILC and repetitive control (RC) algorithms. Longman also provided experimental test results and detailed explanations on the practical uses of ILC. In [283], Moore proved a convergence analysis for ILC systems with a desired periodic output trajectory. The final three papers of the special issue were dedicated to ILC applications: [356] used an H_∞ approach for a wafer positioning control problem, [308] applied ILC to nonholonomic systems, and [35] showed how ILC can be utilized for position control of chain conveyer systems.

2) ILC-Related Ph.D. Dissertations Since 1998: First of all, note that our search for Ph.D. dissertations published since 1998 is very limited, because "Digital Dissertations" does not include all the schools in the world, and we were not able to personally be aware of all the dissertations published everywhere on this topic. Nonetheless, we tried to include all the Ph.D. dissertations of which we were aware. In 2004, the number of Ph.D. dissertations in ILC significantly increased as shown in Table IV. In [176], Hätönen studied the algebraic properties of a standard ILC structure and made progress in the norm-optimal ILC field. Verwoerd [433] suggested equivalent feedback controllers for causal ILC and noncausal ILC based on an admissibility concept. A similar discussion to [433] can be found in [155], [314], and [156]. Dijkstra [103] showed some exciting ILC applications. In his dissertation, lower order ILC has been applied to the different wafer stages. In addition, for finite-time ILC, Dijkstra provided several interesting theoretical developments in [103, Ch. 4]. Oh [306] introduced a local learning concept to avoid undesirable overshoot during the transient. Norrlöf [304] presented a number of useful results on the theory of ILC, including ideas about the use of models in ILC and presentation of a successful ILC application for a robotic manipulator. Markusson [266] used ILC to find an inversion of the system, particulary focused on noncausal and nonminimum systems. A time-frequency adaptive Q-filter ILC was suggested for nonsmooth-nonlinearity compensation

TABLE IV
ILC-RELATED PH.D. DISSERTATIONS

	1998	1999	2000	2001	2002	2003	2004	Total
Number	1	1	3	2	3	0	8	18

[4]http://wwwlib.umi.com/dissertations/gateway

by Zheng in [513], and the idea was used for an injection molding machine. ILC and RC were summarized and some new results for nonlinear nonminimum phase systems were developed by Ghosh in [152]. Yang [499] studied ILC based on neural networks, and in [131], Frueh suggested the basis-function-model-reference adaptive learning controller (see also [130]). The suggested method in [131] has several advantages. One, in particular, is an adaptive property to account for slowly varying plant parameters or errors from the initial model. Huang [200] introduced Fourier- series-based ILC algorithms for the tracking performance improvement. In [446], several important issues from the field of learning and repetitive control were addressed; for example, indirect adaptive control ideas applied to learning control were introduced, and based-functions were used to show that the learning control and the repetitive control problems are mathematically the same under the same conditions. Songchon [385] showed that learning control has the ability to bypass the waterbed effect, which is a fundamental problem in traditional feedback controls. LeVoci [246] developed methods for predicting the final error levels of general first-order ILC, of higher order ILC including current-cycle learning (CCL), and of general RC, in the presence of noise, using frequency response methods. Three main difficulties in the area of linear discrete-time ILC were addressed in [254]: 1) the number of output variables for which zero tracking error can be achieved is limited by the number of input variables; 2) every variable for which zero tracking error is sought must be a measured variable; and 3) in a digital environment, the intersample behavior may have undesirable error from a ripple. As interesting application of optimal ILC was utilized for a chemical molding process in [502]; Ma [261] showed that an ILC algorithm can be used for the vision-based tracking systems; and Phetkong [336] used ILC on a cam designed and built using a 2–3 polynomial profile, and it was shown that eight cycles for learning were seen to be sufficient to effectively accomplish the morphing of the cam behavior.

III. From 1998 to 2004: Categorization

In this section, we separate the literature into two different parts. The first part is related to the literature that focuses on ILC applications, and the second part is related to the literature focused on theoretical developments. Of course, it is often difficult to separate the literature into these two groups, so the categorizations given in this section are largely based on authors' subjective opinions. Also, note that in this section, we do not make detailed comments but simply categorize the papers.

A. Literature Related To ILC Applications

In [275], ILC literature dealing with applications was categorized as "robotics" and "applications." In "robotics," detailed categories were given as "elastic joints," "flexible links," "cartesian coordinates," "neural networks," "cooperating manipulators," "hybrid control," and "nonholonomic." In applications, detailed categories were given as "vehicles," "chemical processing," "mechanical/manufacturing systems," "nuclear reactor," "robotics demonstrations," and "miscellaneous." In this paper, we began by trying to follow the above categories, but found it difficult to restrict all the publications between 1998 and 2004 into the categories given above [275, Table 4.2]. Thus, we make more detailed categories, including "Robots," "Rotary systems," "Batch/factory/chemical processes," "Bio/artificial muscle," "Actuators," "Semiconductors," "Power electronics" and "Miscellaneous," and in each category, we provide further subcategories.

1) Robots: As shown in [275], robotics is the most active area of ILC application. Since 1998, this continues to be the case. Robotic applications of ILC have included:

- general robotic applications, including rigid manipulators and flexible manipulators [19], [34], [93], [158], [166], [167], [193], [194], [204], [210], [211], [213], [219], [224], [252], [292], [301], [379], [389], [417], [418], [494], [503]–[505], [514];
- mechatronics design [429], [448];
- robot applications with adaptive learning [390];
- with Kalman filter [295];
- impedance matching in robotics [30], [44], [289], [436];
- table tennis [268];
- underwater robots [220], [372]–[374];
- acrobat robots [444], [496];
- cutting robots [212];
- mobile robots [67], [279];
- gantry robots [173], [352];
- arc welding process [191];
- microscale robotic deposition [41].

2) Rotary Systems: Rotational motion is generally disturbed by position-dependent or time-periodic external disturbances. Thus, control of rotary systems is a good candidate for ILC application. The papers related to this area include:

- vibration suppression of rotating machinery [249];
- switched reluctance motors (SRM) [367]–[371];
- permanent-magnet synchronous motor (PMSM) [231]–[243], [342]–[344], [460], [461];
- linear motors [408];
- (ultrasonic) induction motor [263], [264], [366];
- AC servo motor [378];
- electrostrictive servo motor [196].

3) Batch/Factory/Chemical Process: The number of ILC applications in process control has increased significantly since 1998. The literature includes:

- tracking control of product quality in agile batch manufacturing processes [238], [452];
- chemical reactor [87], [247], [270], [271], [506];
- water heating system [458];
- laser cutting [428];
- chemical process [40], [145], [183], [413], [456];
- batch process [85], [415], [453], [457];
- industrial extruder plant [319]–[322];
- moving problem of liquid container [162], [163], [353];
- packaging and assembly [39];
- injection molding [72], [411].

4) Bio/Artificial Muscle: Bioengineering or biomedical applications are not yet a popular ILC application area, but slowly, the number of applications is increasing as evidenced by the following:

- biomedical applications such as dental implants [202], [203];

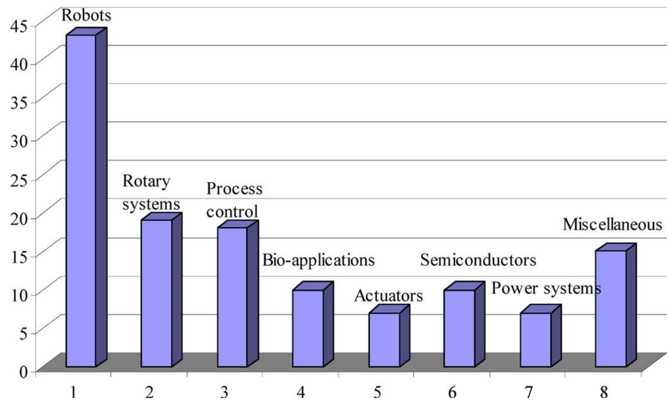

Fig. 3. Publication number of application-focused ILC literature.

- functional nueromuscular stimulation (FNS) application [107], [450];
- human operator [12];
- artificial muscle [195];
- pneumatic system [46];
- smart microwave tube [1], [375];
- biomaterial applications [435].

5) Actuators: ILC applications to nonrobotic/nonmotor actuators are closely related to the mechanical hard-nonlinearity compensation problem discussed in Section III-B8:

- proportional-valve-controlled hydraulic cylinder system [45];
- electromechanical valve [189], [190], [331];
- Hysteresis problem of a piezoelectric actuator [260];
- linear actuators [242], [412].

6) Semiconductor: It is quite interesting to see that ILC is widely applied in the semiconductor production process. Between 2001 and 2003, the following literature was published in semiconductor applications: [84], [86], [92], [99]–[102], [237], [358], [498]. For a more detailed discussion of the application of ILC to semiconductor manufacturing processes, refer to [103].

7) Power Electronics: Examples of ILC applications to electrical power systems can be found in the following:

- electronic/industrial power systems [441], [510]–[512];
- inverters [2], [36].

8) Miscellaneous: Many miscellaneous applications of ILC are described in the following:

- traffic [192];
- magnetic bearing [73], [98];
- aerospace [61], [69];
- linear accelerator [230];
- dynamic load simulator [440];
- hard disk drive [474], [475];
- temperature uniformity control [236], [240], [269];
- visual tracking [251];
- quantum mechanical system [333];
- piezoelectric tube scanner [188].

Fig. 3 plots the number of papers focused on the use of ILC in applications. As shown in Fig. 3, ILC has most dominantly been applied to the area of robotics. However, notably, ILC has also been widely used in rotational motion control systems, in the process control industry, and for semiconductor manufacturing processes.

We also note that to check the practical uses of ILC, we searched U.S. patent abstracts using the keywords "Iterative" AND "Learning."[5] From this search, we found ILC-related patents in motor control [341], process control [160], disk-drive control [68], and network communication [218].

B. Literature Related to ILC Theories

Since the spectrum of the theoretical developments is so broad and individual papers often treat several different topics, assigning a given paper to a specific category can be quite subjective. Our approach was to try to separate papers that considered ILC as a specific topic from those that connected ILC analysis to other control theory topics. Our general categories were defined as "General (Structure)," "General (Update Rules)," "Typical ILC Problems," "Robustness," "Optimal and Optimization," "Adaptive," "Fuzzy and Neural," "Mechanical Nonlinearity Compensation," "ILC for Other Repetitive Systems and Control Schemes," and "Miscellaneous." The first three categories are related to unique ILC problems (i.e., ILC's own issues not related to other control theories). The next four categories (robust, optimal, adaptive, fuzzy/neural) are for papers that combine or use results from these specific fields to advance the theoretical developments of ILC. The next two categories consider special cases where ILC has been applied to develop theoretical solutions to these special problem classes (mechanical nonlinearity, repetitive control) and the final category collects miscellaneous contributions.

1) General (Structure): In this category, we include literature related to "ILC structure," "convergence analysis," "stability analysis," and "basic theoretical works." In [316], Owens studied an ILC algorithm using the following update rule:

$$u_{k+1}(t) = \alpha u_k(t) + K e_{k+1}(t) \tag{26}$$

which leads to the steady-state error expression $e_\infty = (I + GK_{\text{eff}})^{-1} y_d$, where G is a plant, y_d is the desired trajectory, and $K_{\text{eff}} = K/(1-\alpha)$. Relationships were given between the steady-state error, the learning gains, and the structure of the ILC system. In [155], [156], and [314], the equivalence of current-cycle (single iteration) feedback control and ILC was discussed. Goldsmith showed that a learning controller updated by $u_k = F u_{k-1} + C e_k + D e_{k-1}$ is equivalent to a feedback controller $u(t) = K e(t-1)$ if K is determined by $K = (I-F)^{-1}(C+D)$. This result is intuitively true and implies that the iterative learning controller is also eventually a feedback controller, based on the fact that ILC is a controller for finding the best feedforward gain in the time domain and the best feedback controller in the iteration domain. In [29], Arimoto and Naniwa used a positive real condition on the plant for defining passivity and output-dissipativity of LTI ILC systems. The ILC convergence was then proved based on the strictly proper and positive realness of the plant in [29, Th. 1] and uniform convergence was proved in [29, Th. 2]. Eventually, this convergence can be interpreted as learnability, which is defined as the existence of a function norm $\|\cdot\|$ such that $\|y_d - y_k\| \to 0$ as $k \to \infty$. In [172], Hätönen *et al.* showed that if a plant G is positive (i.e., $\exists\, \sigma > 0$ such

[5] http://patft.uspto.gov/netahtml/search-bool.html

that $u^T Gu \geq \sigma u^T u$ for any $u \neq 0$), then for the ILC system updated by $u_{k+1}(t) = u_k(t) + \gamma_{k+1} e_k(t+1)$ with learning gain $\gamma_{k+1} = (e_k^T G e_k)/(w + e_k^T G^T G e_k)$, the resulting error sequence satisfies $e_k \to 0$ as $k \to \infty$. In [256], Longman and Huang discussed the large overshoots in the transient response that can occur in ILC even when the system is asymptotically converegent. They noted that the trajectory error of the first iteration can be separated into two different frequency areas: low frequency and higher frequency. ILC initially learns the low-frequency area where the majority of error stays, but the remaining higher frequency errors grow as the number of iterations increases, which generates divergence in the intermediate trials until the higher frequencies can be learned. Thus, the large overshoots that can occur in the learning transient depends on the initial error, which depend on the desired trajectory and time-domain feedback control scheme. For more detailed papers related to structure issues, see the following:

- structure [169], [175], [315], [316], [332], [424];
- equivalence of ILC to one-step minimum prediction control or feedback control [153]–[157], [277], [314], [432];
- analysis in the point of passivity (dissipativity) [22]–[24], [29], [31], [288];
- analysis in the point of positivity [139], [171], [172];
- divergence observation [256];
- steady-state oscillation condition and its utilization [222];
- strongly positive system [10], [11].

2) General (Update Rules): In this category, we include literature that discusses "ILC update rules" and their "performance comparisons." Eventually, in ILC, the control force can be updated by

$$\begin{aligned} u_{k+1}(t) &= \underbrace{\sum_{i=k}^{i=k-l}\sum_{j=0}^{j=n} \lambda_i(j)u_i(j) + \sum_{i=k}^{i=k-l}\sum_{j=0}^{j=n} \gamma_i(j)(y_d(j) - y_i(j))}_{A} \\ &\quad + \underbrace{\sum_{j=0}^{j=t-1} \lambda_{k+1}(j)u_{k+1}(j) + \sum_{j=0}^{j=t-1} \gamma_{k+1}(j)(y_d(j) - y_{k+1}(j))}_{B} \\ &\quad + \underbrace{\sum_{j=t}^{j=n} \lambda_{k+1}(j)u_{k+1}(j) + \sum_{j=t}^{j=n} \gamma_{k+1}(j)(y_d(j) - y_{k+1}(j))}_{C} \end{aligned} \tag{27}$$

where A is for first-order and higher order schemes, B is for current cycle update, and C is for anticipatory update. It is also natural to include D-type and I-type terms into (27) using the past error signals. When we consider the continuous case, these D-type and I-type can be also updated in a fractional way [54]. In [32], a Broyden-update rule was used by solving the optimization problem

$$P_{k+1} = \arg\min_P \|P - P_k\|$$

where P_k is the learning gain matrix for the kth iteration used in the update law $u_{k+1} = u_k - P_k^{-1} e_k$. In [118], [120], and [229], there was a debate about a control law that ensures a zero output error for the whole desired trajectory after only one iteration trial. In these papers, they claimed that zero error can be assured only using the information about B and C matrices. Other debates have centered on the value of HOILC. In [293], a first-order ILC algorithm and a second-order ILC algorithm were compared. From an industrial robot test, Norrlöf concluded that "it is not possible to say that a second-order ILC algorithm does better than a first-order algorithm." However, Norrlöf also added that the second-order ILC scheme is very competitive when there is an uncertainty in the plant that makes the plant different between the iterations. Furthermore, he found that the second-order algorithm could smooth the behavior of the system by using the control and the error signal from more than one iteration. In [459], Xu *et al.* compared previous-cycle learning (PCL), CCL, and synergetic previous- and current-cycle learning (PCCL). The conclusion was that PCCL has a better performance than PCL or CCL. Also, as remarked in the conclusion of [459], it was highlighted that ILC robustness can be enhanced by incorporating a current-cycle feedback. For various other ILC update rules, refer to the following categories:

- update rules such as D-type ILC, P-type ILC, I-type ILC, PD-type ILC, and PID-type [57], [174], [380], [381], [463], [497], [509];
- fractional [54];
- using current cycle [338];
- anticipatory [437];
- update in Hilbert space [32], [33];
- performance guaranteed ILC, convergence speed improvement, or performance improvement [66], [104], [118], [120], [186], [229], [423], [465], [471], [472], [477];
- linearization [184];
- automated/self tuning [258], [262], [447];
- comparison of ILC update rules [293], [459], [464], [476];
- discussion on convergence and/or robustness [233], [303], [307], [479].

3) Typical ILC Problems: In this category, we include ILC problems such as nonminimum phase, initial condition reset, higher order approach, 2-D analysis, and frequency-domain analysis. From [275, Table 4.1], it is shown that these typical ILC problems had been popularly studied before 1997. But, we can observe that many publications are still devoted to these topics. It has been widely accepted that ILC can be very effective in controlling a nonminimum phase system because it uses noncausal filters (in traditional control theory, if a plant is nonminimum phase, perfect tracking cannot be achieved using causal operators). In [151], Ghosh and Paden designed a pseudoinverse-based learning controller for the following nonlinear (could be nonminimum phase) affine system with disturbance:

$$\dot{x}_k(t) = f(x_k(t)) + g(x_k(t))u_k(t) + b(x_k(t))w_k(t), \quad x_k(0) = 0 \tag{28}$$

$$y_k(t) = h(x_k(t)) + v_k(t) \tag{29}$$

where $w_k(t)$ includes both repetitive and random-bounded disturbances. For solving this problem, Ghosh and Paden linearized the nonlinear system around the nominal plant using a first-order Taylor series and then used the pseudoinverse of this linearized plant for the control force propagation. In [205], an input update law, which depends on the number of nonminimum phase zeros, was proposed using an iterative learning control scheme with advanced output data (ADILC). In [305], Ogoshi *et al.* used input–output linearization for the ILC system design of the nonlinear nonminimum phase system (28), (29) (but without noise and disturbance). Sogo provided a stable inversion filter with a noncausal operation [382, Ex. 1] and Verwoerd *et al.* [431] concluded that noncausal ILC outperforms causal ILC, and ILC can be very effective in cases where the causality constraint imposed by the closed loop is the limiting factor.

Initial condition reset is one of the most critical assumptions of ILC. Many publications have been devoted to relaxing this critical assumption. For example, Sun and Wang provided an analysis about initial reset for a nonlinear continuous ILC system [397] and for a nonlinear discrete ILC system [398], and suggested initial rectifying actions to improve the tracking performance. In [323], Park and Bien showed for both linear and nonlinear systems that $\lim_{k\to\infty} y_k(t) = y_d(t) - \overline{e}(t)$, where $\overline{e}(t)$ is analytically determined from the initial reset error.

HOILC has been steadily studied for improving convergence speed and robustness [223]. In ILC, 2-D analysis has also been studied for a long time. The first 2-D approach in ILC field is [228], which was developed based on Kurek's earlier work [227]. Recently, Fang and Chow [119] used 2-D theory for handling the initial reset problem of ILC. In fact, ILC system is a 2-D system in nature. French *et al.* [128] developed an adaptive iterative learning algorithm based on 2-D concept, and Owens *et al.* [317] comprehensively explained the stability of HOILC scheme, norm-optimal ILC, predictive norm-optimal ILC, and adaptive ILC based on 2-D concepts.

In [346], a frequency-domain-based learning update rule was introduced for the tracking control of a tooth-belt driven positioning table. For this purpose, a continuous periodic signal is approximated by discrete Fourier transform (DFT); then they use a feedback controller (PD control) and feedforward learning control for the control force calculation according to

$$u(t) = PD(t) + \hat{u}(t). \tag{30}$$

Then, transforming (30) into the discrete frequency domain, they proved the convergence of a frequency-domain-based update rule (actually the proof was given in [416]). In [117], a frequency-domain-based stability analysis was given, by which the following two conditions need to be satisfied:

$$\begin{aligned} &|1 - e^{jwT}\phi G(e^{jwT})| < 1, && \forall w \text{ (for SISO)} \\ &\overline{\sigma}[1 - e^{jwT}\phi G(e^{jwT})] < 1, && \forall w \text{ (for MIMO)} \end{aligned} \tag{31}$$

where ϕ is the learning gain (matrix). Since the inequality boundary of (31) is a unit circle centered at $+1$ in the Nyquist polar plot of $z\phi G(z)$, it was noted that the poor transient problem is due to the frequency range where the Nyquist plot is outside the unit circle. For eliminating this frequency range, it was concluded that a cutoff is needed, and it was claimed that the cutoff is also necessary for good transient robustness. For a similar frequency-domain-based stability analysis, refer to [299]. Additional papers related to typical ILC problems include:

- nonminimum phase and/or noncausal filter [90], [122], [123], [147], [150], [151], [205], [207], [208], [225], [226], [265], [291], [305], [382], [383], [431];
- inverse model based or pseudoinverse-based ILC [148], [149], [290];
- initial setting (shift) [71], [121], [323], [325], [393], [396]–[398], [401], [402], [405], [500];
- HOILC [6], [70], [223], [281], [300], [334], [478];
- 2-D approach/analysis [96], [112]–[114], [119], [128], [139], [141], [142], [161], [276], [317], [354];
- frequency-domain analysis and/or synthesis based on frequency-based filtering [51], [52], [64], [117], [244], [248], [298], [299], [302], [339], [346], [384].

4) Robustness Against Uncertainty, Time-Varying, and/or Stochastic Noise: This category includes robustness problems such as disturbance rejection, stochastic affects, H_∞ approaches, etc. Arif *et al.* [15] used the update rule $u_{k+1}(t) = u_k(t) + \Gamma_1 \dot{e}_k(t) + \Gamma_2 \dot{e}_{k+1}(t)$ where $\dot{e}_{k+1}(t)$ is the predicted error, to improve the ILC convergence speed for time-varying linear systems with unknown but bounded disturbances. In [425], time-periodic disturbances and nonstructured disturbances were compensated using a simple recursive technique that does not use Lyapunov equation (refer to [469] for disturbance compensation using Lyapunov functions). For general ideas about robust ILC, refer to [273] for the linear case and see [74], [337], [419], [421], [439], [482], and [492] for the nonlinear case. Other related papers include:

- disturbance rejection with feedback control [83];
- disturbance rejection with iteration-varying filter [297];
- nonlinear stochastic systems with unknown dynamics and unknown noise statistics [49];
- stochastic ILC [48], [362]–[365] and with error prediction [15];
- measurement noise [287], [296];
- H_∞ approach [330];
- μ-synthesis [105], [106];
- model-based [21], [351];
- based on backstepping ideas [425];
- polytope uncertainty approach [250].

5) Optimal, Quadratic, and/or Optimization: Optimal ILC is considered as one of the main ILC theoretical areas, and it has a well-established research history. Norm-optimal ILC is due to [137], as commented in [177]. Recently, there have been several different quadratic-cost-function-based ILC algorithms. In this category, we consider these algorithms and other optimization-based methods. Amann *et al.* [8] proposed the so-called norm-optimal controller to determine a control force at the $(k+1)$th iteration by minimizing the following cost function:

$$J_{k+1,N}(u_{k+1}) = \sum_{i=1}^{N} \lambda^{i-1}(\|e_{k+i}\|^2 + \|u_{k+i} - u_{k+i-1}\|^2) \tag{32}$$

where the weigh parameter λ determines the importance of more distant (future) errors and incremental inputs compared with the present ones. We note that (32) uses the next N trials' information (compare with the anticipatory algorithm [437]). In [8], an optimal control force is calculated as $u_{k+1} = u_k + G^*(I + \lambda Q_{N-1})e_{k+1}$, where e_{k+1} is recursively updated by $e_{k+1} = [I + GG^*(I + \lambda Q_{N-1})]^{-1}e_k$ and Q_N is also recursively updated by $Q_N = [I + GG^*(I + \lambda Q_{N-1})]^{-1}(I + \lambda Q_{n-1})$. Gunnarsson and Norrlöf [164] interpreted the norm-optimal ILC in the frequency domain, and recently, in [177], norm-optimal

ILC was used with a genetic algorithm for calculating the optimal learning gain for a class of nonlinear ILC problems. In [311], optimality-based adaptive ILC algorithms were developed. For nonlinear systems, Choi and Jang [89] used the steepest gradient method for minimizing a performance index function, and in [221], singular value decomposition was used for analyzing a quadratic-form-based optimal ILC algorithm. Other related references include:

- optimal ILC [4], [5], [8], [164], [170], [177]–[182], [310], [311], [360], [361], [427];
- linear quadratic optimization-based method [159], [309];
- quadratic cost function-based method [89], [129], [221], [235];
- numerical optimization [267].

6) Adaptive Control and/or Adaptive Approaches: Adaptive-control-based ILC is very popular, and many theoretical works in ILC are related to Lyapunov functions and/or adaptive control concepts. In this category, we only include the literature, which focuses on purely theoretical adaptive ILC. For robot manipulator control, adaptive learning control has been very popular. For example, in [391], an adaptive learning (A-L) control scheme was developed for robot manipulator tracking; in [272], Miyasato proposed a hybrid adaptive control scheme (enhanced by ILC), and in [94], Choi and Lee provided a hybrid adaptive learning control scheme using both feedback control and feedforward control for robot manipulation. For nonrobotic adaptive-control-based ILC, in [125], French and Rogers consider the following system:

$$\dot{x}_i = x_{i+1}, \qquad i = 1, \ldots, n-1$$
$$\dot{x}_n = \theta^T \phi(x) + u$$

where $\phi(x)$ is known, and $\theta \in \mathcal{R}^n$ are unknown parameters. If $\widehat{\theta}$ are the adaptively estimated parameters, it was shown that $\widehat{\theta}$ can be estimated such that $(\theta - \widehat{\theta})^T(\theta - \widehat{\theta})$ is monotonically decreasing in a finite time horizon. Owens *et al.* [318] used an adaptation learning gain update law, and French *et al.* [124] further provided a learning control scheme based on learning gain adaptation, using only the information of $\mathrm{sign}(BC)$. In [76], a model reference adaptive control scheme for an affine nonlinear ILC system was developed based on output-feedback linearization, and in [241], a discrete-time model reference adaptive learning control scheme was developed for a linear system. Other publications studying adaptive control-based ILC include:

- general works [47], [50], [77], [94], [124], [125], [127], [272], [294], [318], [391], [501];
- model reference [76], [241];
- model reference with basis functions [335], [445].

7) Fuzzy or Neural Network ILC: In the ILC literature, it has been shown that learning gains can be determined from neural network or fuzzy logic schemes [274]. Specific results include:

- fuzzy ILC and fuzzy ILC for initial setting [7], [75], [82], [340], [376], [442], [486], [508];
- feedforward controller (LFFC) using a dilated B-spline network [59], [430];
- artificial neural networks for ILC and ILC applied to neural networks [80], [81], [95], [97], [185], [198], [209], [214], [215], [253], [377], [409], [414], [443], [451], [485], [495].

8) ILC for Mechanical Nonlinearity Compensation: Many ILC publications show that mechanical hard nonlinearities can be compensated successfully if they have some sort of periodicity in the time-, state-, or frequency-domain. The main idea of hard-nonlinearity compensation is to analyze stability in the iteration domain as done in [391]. That is, in the first iteration, we need to guarantee bounded-input bounded-output in an l_p norm topology. Then, from the second iteration onward, asymptotic stability should be guaranteed as a function of iteration. Even though the main idea can be found in [480], the following publications can be referred to for stability analysis of specific hard-nonlinearity compensation strategies using ILC:

- ILC without *a priori* knowledge of control direction and with non-Lipschitz disturbance [217], [469], [490];
- ILC with input saturation [466], [481];
- input singularity [468], [489];
- deadzone [216], [359], [493];
- Coulomb friction [108], [109], [111], [146];
- using Smith predictor for time delay and disturbance system [197], [473];
- delay [324], [329], [394];
- backlash [201].

9) ILC for Other Repetitive Systems and Control Schemes: Though classical control theories have been utilized for ILC performance improvement, it is also possible to use ILC theory for the performance improvement of other control schemes. Using the general idea of ILC, the performances of several other types of control strategies have been improved, including: repetitive control, PID, optimal control, neural network, etc., [18], [43], [91], [143], [199], [206], [313], [434]; and model-based predictive control [234], [239].

10) Miscellaneous: Papers that we cannot separate into the categories 1–9 include:

- different tracking control tasks [467];
- slowly-varying trajectory and/or direct learning control (DLC) for nonrepeatable reference trajectory, or DLC for MIMO [3], [13], [17], [482], [486], [487];
- LMI ILC [138], [140], [144], [355], [388];
- monotonic ILC [56], [278], [280], [284], [286], [327], [328];
- Hamiltonian control systems [132]–[136];
- MIMO linear time-varying system ILC [410];
- observer-based ILC [419];
- blended multiple model ILC [420];
- composite energy function ILC [462], [487];
- cascaded nonlinear system [347], [349];
- nonlinear with constraint [53];
- maximum phase nonlinear system [88];
- unknown relative degree [392]; and arbitrary or higher relative degree [20], [78], [403], [507];
- decentralized iterative learning control [449];
- internal model-based [55], [58], [422], [426], [491];
- distributed parameter systems [348], [350];
- ILC with prescribed input–output subspace [165], [168]; with desired input in an appropriate finite dimensional input subspace [386], [387]; and with bounded input [110];

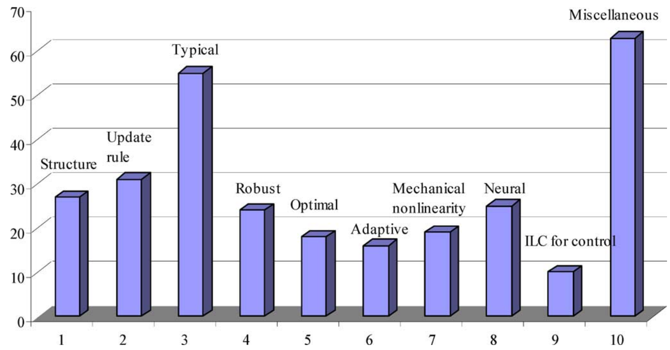

Fig. 4. Publication number of theory-focused ILC literature.

- sampled data ILC [395], [399]–[401], [404], [406], [407];
- experience/information database [13], [14], [16];
- Fourier series based learning controller [345];
- learning variable structure control [470];
- with weighted local symmetrical integral feedback controller [63];
- inter-sampling error [245];
- model identification [255], [257].

Fig. 4 plots the number of papers related to the theoretical developments in ILC. As seen in Fig. 4, the ILC theory has been advanced by being connected to existing control theories such as robust, adaptive, optimal, and neural/fuzzy control. However, the ILC structure and update problems, which are investigated within ILC's own framework, dealing with ILC problems such as the nonminimum phase systems, the initial reset problem, the higher-order issue, 2-D analysis, and convergence/performance improvement, have been more widely studied. Fig. 4 reveals that lot of research is still devoted to ILC's own theoretical and structural problems. It is also interesting to point out that while other control schemes have been used to help improve ILC, in the same way, the ILC concept has been used for improvement in performance of other control schemes.

IV. Discussions and Conclusion

In this paper, we have categorized and discussed the ILC literature published between 1998 and 2004. Following a general introduction to ILC and a technical description of the methodology, selected results were reviewed, and we then categorized the ILC literature into two broad divisions: application and theory.

From the categorization of application-related literature, we have found that ILC applications have been extended from robotics and process control to more specific semiconductor manufacturing and bioengineering applications. However, applications remain dominated by manipulator-based robotics, rotary systems, and process control problems, which are basically time- or state-periodic in either the desired trajectory or the external disturbances. Although some of the publications have shown that ILC can be used in the areas of aerospace, nonrobotic actuator control, biomedical applications, visual tracking, artificial muscles, and other emerging engineering problems, successful industrial applications have not yet been reported in these areas.

From the survey of theory-focused literature, it is seen that ILC theory has been developed in two different areas: research on ILC's own features, and research on ILC systems fused with other control theories. Most of the recent theoretical work has been related to performance improvement with various types of uncertainties and/or instabilities. However, although many recent theoretical achievements have provided beautiful mathematical formulations of ILC, much of the theoretical development remains far away from actual application considerations. From our observations, we would argue that it is more urgent to develop theoretical ILC works to support industrial ILC application, where the robust performance issues on the iteration domain may be more important.

As a disclaimer, we would note again that while we tried to include as many ILC publications as we could find, the literature search was restricted to the exact name of "iterative learning control." Thus, it is certain that we have missed many important ILC publications. Nonetheless, we believe that the survey work performed in this paper can help the reader understand the overall trend of ILC in both applications and theory. We would finally repeat that research in ILC applications is still not so active as compared with purely theoretical works. Thus, it is our hope to see more publications that include successful ILC experimental results and/or industrial applications. In this respect, we hope that the next ILC survey to appear will find that more papers such as [259] will have been published.

Acknowledgment

The authors would like to thank the anonymous reviewers for their constructive comments which improved the presentation of this paper. The first author also appreciates Min-Hui Kim for her help in generating the statistics presented in the paper.

References

[1] C. T. Abdallah, V. S. Soualian, and E. Schamiloglu, "Toward "smart tubes" using iterative learning control," *IEEE Trans. Plasma Sci.*, vol. 26, no. 3, pp. 905–911, Jun 1998.

[2] S. M. Abu-Sharkh, Z. F. Hussien, and J. K Sykulski, "Current control of three-phase PWM inverters for embedded generators," in *Proc. 8th Int. Conf. Power Electron. Variable Speed Drives*, London, U.K., Sep. 2000, pp. 524–529.

[3] H.-S. Ahn, J.-M. Park, D.-H. Kim, I. Choy, J.-H. Song, and M. Tomizuka, "Extended direct learning control for multi-input multi-output nonlinear systems," in *Proc. IFAC 15th World Congr.*, Barcelona, Spain, Jul. 2002, pp. 2989–2994.

[4] T. Al-Towaim, A. D. Barton, P. L. Lewin, E. Rogers, and D. H. Owens, "Iterative learning control—2D control systems from theory to application," *Int. J. Control*, vol. 77, no. 9, pp. 877–893, 2004.

[5] T. Al-Towaim, P. Lewin, and E. Rogers, "Norm optimal iterative learning control applied to chain conveyor systems," in *Proc. IFAC Workshop Adapt. Learn. Control Signal Process.*, 2001, pp. 95–99.

[6] T. Al-Towaim, P. L. Lewin, and E. Rogers, "Higher order ILC versus alternatives applied to chain conveyor systems," presented at then IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.

[7] P. Albertos, M. Olivares, and A. Sala, "Fuzzy logic based look-up table controller with generalization," in *Proc. 2000 Amer. Control Conf.*, Chicago, IL, Jun. 2000, pp. 1949–1953.

[8] N. Amann, D. H. Owens, and E. Rogers, "Predictive optimal iterative learning control," *Int. J. Control*, vol. 69, no. 2, pp. 203–226, 1998.

[9] N. Amann, H. Owens, and E. Rogers, "Iterative learning control for discrete-time systems with exponential rate of convergence," *Proc. Inst. Elect. Eng.—Control Theory Appl.*, Mar. 1996, vol. 143, no. 2, pp. 217–224.

[10] D. Andres and M. Pandit, "Convergence and robustness of iterative learning control for strongly positive systems," in *Proc. 3rd Asian Control Conf.*, Shanghai, China, 2000, pp. 1866–1871.

[11] D. Andres and M. Pandit, "Convergence and robustness of iterative learning control for strongly positive systems," *Asian J. Control*, vol. 4, no. 1, pp. 1–10, 2002.

[12] M. Arif and H. Inooka, "Iterative manual control model of human operator," *Biol. Cybern.*, vol. 81, no. 5–6, pp. 445–455, 1999.

[13] M. Arif, T. Ishihara, and H. Inooka, "Application of PILC to uncertain nonlinear systems for slowly varying desired trajectories," in *Proc. 37th SICE Annu. Conf.*, Chiba, Japan, Jul.1998, pp. 991–994.

[14] M. Arif, T. Ishihara, and H. Inooka, "Iterative learning control using information database (ILCID)," *J. Intell. Robtic Syst.*, vol. 25, no. 1, pp. 27–41, 1999.

[15] M. Arif, T. Ishihara, and H. Inooka, "Iterative learning control utilizing the error prediction method," *J. Intell. Robtic Syst.*, vol. 25, no. 2, pp. 95–108, 1999.

[16] M. Arif, T. Ishihara, and H. Inooka, "Using experience to get better convergence in iterative learning control," in *38th Annu. Conf. Proc. SICE Annu.*, Morioka, Japan, Jul.1999, pp. 1211–1214.

[17] M. Arif, T. Ishihara, and H. Inooka, "Prediction-based iterative learning control (PILC) for uncertain dynamic nonlinear systems using system identification technique," *J. Intell. Robot. Syst.*, vol. 27, no. 3, pp. 291–304, 2000.

[18] M. Arif, T. Ishihara, and H. Inooka, "Incorporation of experience in iterative learning controllers using locally weighted learning," *Automatica*, vol. 37, no. 6, pp. 881–888, 2001.

[19] M. Arif, T. Ishihara, and H. Inooka, "Experience-based iterative learning controllers for robotic systems," *J. Intell. Robot. Syst.*, vol. 35, no. 4, pp. 381–396, 2002.

[20] M. Arif, T. Ishihara, and H. Inooka, "A learning control for a class of linear time varying systems using double differential of error," *J. Intell. Robot. Syst.*, vol. 36, no. 2, pp. 223–234, 2003.

[21] M. Arif, T. Ishihara, and H. Inooka, "Model based iterative learning control (MILC) for uncertain dynamic non-linear systems," in *Proc. 14th World Congr. IFAC*, Beijing, China, 1999, pp. 459–564.

[22] S. Arimoto, "Equivalence of learnability to output-dissipativity and application for control of nonlinear mechanical systems," in *1999 IEEE Int. Conf. Syst., Man, Cybern.*, Tokyo, Japan, Oct., vol. 5, pp. 39–44.

[23] S. Arimoto, H. Y. Han, P. T. A. Nguyen, and S. Kawamura, "Iterative learning of impedance control from the viewpoint of passivity," *Int. J. Robust Nonlinear Control*, vol. 10, no. 8, pp. 597–609, 2000.

[24] S. Arimoto, S. Kawamura, and H.-Y. Han, "System structure rendering iterative learning convergent," in *Proc. 37th IEEE Conf. Decision Control*, Tampa, FL, Dec.1998, pp. 672–677.

[25] S. Arimoto, S. Kawamura, and F. Miyazaki, "Bettering operation of dynamic systems by learning: A new control theory for servomechanism or mechatronic systems," in *Proc. 23rd Conf. Decision Control*, Las Vegas, NV, Dec.1984, pp. 1064–1069.

[26] S. Arimoto, S. Kawamura, and F. Miyazaki, "Bettering operation of robots by learning," *J. Robot. Syst.*, vol. 1, no. 2, pp. 123–140, 1984.

[27] S. Arimoto, S. Kawamura, and F. Miyazaki, "Convergence, stability and robustness of learning control schemes for robot manipulators," in *Recent Trends in Robotics: Modelling, Control, and Education*, M. J. Jamishidi, L. Y. Luh, and M. Shahinpoor, Eds. Amsterdam, The Netherlands: Elsevier, 1986, pp. 307–316.

[28] S. Arimoto and T. Naniwa, "Equivalence relations between learnability, output-dissipativity and strict positive realness," *Int. J. Control*, vol. 73, no. 10, pp. 824–831, 2000.

[29] S. Arimoto and T. Naniwa, "Learnability and adaptability from the viewpoint of passivity analysis," *Intell. Autom. Soft Comput.*, vol. 8, no. 2, pp. 71–94, 2002.

[30] S. Arimoto, P. T. A. Nguyen, and T. Naniwa, "Learning of robot tasks via impedance matching," in *Proc. IEEE Int. Conf. Robot. Autom.*, Detroit, MI, May1999, pp. 2786–2792.

[31] S. Arimoto and P. T. A. Nguyen, "Iterative learning based on output-dissipativity," in *Proc. 3rd Asian Control Conf.*, Shanghai, China, 2000, pp. 2909–2914.

[32] K. E. Avrachenkov, H. S. M. Beigi, and R. W. Longman, "Updating procedures for iterative learning control in Hilbert space," *Intell. Autom. Soft Comput.*, vol. 8, no. 2, pp. 183–189, 2002.

[33] K. E. Avrachenkov, H. S. M. Beigi, and R. W. Longman, "Updating procedures for iterative learning control in Hilbert space," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec.1999, pp. 276–280.

[34] A. AZenha, "Iterative learning in variable structure position/force hybrid control of manipulators," *Robotica*, vol. 18, no. 2, pp. 213–217, 2000.

[35] A. D. Barton, P. L. Lewin, and D. J. Brown, "Practical implementation of a real-time iterative learning position controller," *Int. J. Control*, vol. 73, no. 10, pp. 992–999, 2000.

[36] L. Ben-brahim, M. Benammar, and M. A. Alhamadi, "A new iterative learning control method for PWM inverter current regulation," in *Proc. 5th Int. Conf. Power Electron. Drive Syst.*, Nov. 2003, pp. 1460–1465.

[37] Z. Bien and K. M. Huh, "Higher-order iterative control algorithm," in *IEEE Proc. Part D, Control Theory Appl.*, May 1989, vol. 136, no. 3, pp. 105–112.

[38] Z. Bien and J.-X. Xu, *Iterative Learning Control—Analysis, Design, Integration and Applications*. Norwell, MA: Kluwer Academic, 1998.

[39] A. Blom, P. Dunias, P. van Engen, W. Hoving, and J. de Kramer, "Process spread reduction of laser microspot welding of thin copper parts using real-time control," in *Proc. Photon Proc. Microelectron. Photon. II*, Bellingham, WA, Jan. 2003, pp. 493–507.

[40] E. Bonanomi, J. Sefcik, M. Morari, and M. Morbidelli, "Analysis and control of a turbulent coagulator," *Ind. Eng. Chem. Res.*, vol. 43, no. 19, pp. 6112–6124, 2004.

[41] D. A. Bristow and A. G. Alleyne, "A Manufacturing system for microscale robotic deposition," in *Proc. 2003 Amer. Control Conf.*, Jun., pp. 2620–2625.

[42] D. A. Bristow, M. Tharayil, and A. G. Alleyne, "A survey of iterative learning control: A learning-based method for high-performance tracking control," *IEEE Control Syst. Mag.*, vol. 26, no. 3, pp. 96–114, Mar. 2006.

[43] C. C. Cheah, "Robustness of time-scale learning of robot motions to uncertainty in acquired knowledge," *J. Robot. Syst.*, vol. 18, no. 10, pp. 599–608, 2001.

[44] C. C. Cheah and D. W. Wang, "Learning impedance control for robotic Manipulators," *IEEE Trans. Robot. Autom.*, vol. 14, no. 3, pp. 452–465, Mar. 1998.

[45] C. K. Chen and W. C. Zeng, "The iterative learning control for the position tracking of the hydraulic cylinder," *JSME Int. J. Series C-Mech. Syst. Mach. Elements Manuf.*, vol. 46, no. 2, pp. 720–726, 2003.

[46] C.-K. Chen and J. Hwang, "PD-type iterative learning control for trajectory tracking of a pneumatic X-Y table with disturbances," in *Proc. 2004 IEEE Int. Conf. Robot. Autom.*, Apr. 26–May 1, pp. 3500–3505.

[47] H. Chen and P. Jiang, "Adaptive iterative feedback control for nonlinear system with unknown control gain," *Control Theory Appl.*, vol. 20, no. 5, pp. 691–694, 2003.

[48] H. F. Chen, "Almost sure convergence of iterative learning control for stochastic systems," *Sci. China Series F—Inf. Sci.*, vol. 46, no. 1, pp. 67–79, 2003.

[49] H. F. Chen and H. T. Fang, "Output tracking for nonlinear stochastic systems by iterative learning control," *IEEE Trans. Autom. Control*, vol. 49, no. 4, pp. 583–588, Apr. 2004.

[50] H. Chen and P. Jiang, "Adaptive iterative feedback control for nonlinear system with unknown high-frequency gain," in *Proc. 4th World Congr. Intell. Control Autom.*, Jun. 2002, pp. 847–851.

[51] K. Chen and R. W. Longman, "Creating a short time equivalent of frequency cutoff for robustness in learning control," in *Proc. Spaceflight Mech.*, San Diego, CA, Feb. 2003, pp. 95–114.

[52] K. Chen and R. W. Longman, "Creating a short time equivalent of frequency cutoff for robustness in learning control," *Adv. Astronautical Sci.*, vol. 114, pp. 95–114, 2003.

[53] W. Chen, Y. C. Soh, and C. W. Yin, "Iterative learning control for constrained nonlinear systems," *Int. J. Syst. Sci.*, vol. 30, no. 6, pp. 659–664, 1999.

[54] Y. Q. Chen and K. L. Moore, "On D° type iterative learning control," in *Proc. 40th IEEE Conf. Decision Control*, Orlando, FL, Dec. 2001, pp. 4451–4456.

[55] Y. Q. Chen and K. L. Moore, "Harnessing the nonrepetitiveness in iterative learning control," in *Proc. 41st IEEE Conf. Decision Control*, Las Vegas, NV, Dec. 2002, pp. 3350–3355.

[56] Y. Q. Chen and K. L. Moore, "An optimal design of PD-type iterative learning control with monotonic convergence," in *Proc. 2002 IEEE Int. Symp. Intell. Control*, Vancouver, BC, Canada, Oct., pp. 55–60.

[57] Y. Q Chen and K. L. Moore, "PI-type iterative learning control revisited," in *Proc. 2002 Amer. Control Conf.*, May, pp. 2138–2143.

[58] Y. Q. Chen and K. L. Moore, "Iterative learning control with iteration-domain adaptive feedforward compensation," in *Proc. 42nd IEEE Conf. Decision Control*, Maui, HI, Dec. 2003, pp. 4416–4421.

[59] Y. Q. Chen, K. L. Moore, and V. Bahl, "Learning feedforward control using a dilated B-spline network: Frequency domain analysis and design," *IEEE Trans. Neural Netw.*, vol. 15, no. 2, pp. 355–366, Mar. 2004.

[60] Y. Q. Chen and C. Wen, "Iterative learning control: Convergence, robustness and applications," in *Lecture Notes on Control and Information Science*, vol. 248, London, U.K.: Springer-Verlag, 1999.

[61] Y. Q. Chen, C. Y. Wen, J. X. Xu, and M. X. Sun, "High-order iterative learning identification of projectile's aerodynamic drag coefficient curve from radar measured velocity data," *IEEE Trans. Control Syst. Technol.*, vol. 6, no. 4, pp. 563–570, Jul. 1998.

[62] Y. Q. Chen, "High-order iterative learning control: Convergence, robustness and applications," Ph.D. dissertation, Nanyang Technol. Univ., Singapore, 1997.

[63] Y. Q. Chen, H. Dou, and K.-K. Tan, "Iterative learning control via weighted local-symmetrical-integration," *Asian J. Control*, vol. 3, no. 4, pp. 352–356, 2001.

[64] Y. Q. Chen and K. L. Moore, "Frequency domain adaptive learning feedforward control," in *Proc. 2001 IEEE Int. Symp. Comput. Intell. Robot. Autom.*, 29 Jul.–1 Aug., pp. 396–401.

[65] Y. Q. Chen and K. L. Moore, "Comments on United States patent 3,555,252—learning control of actuators in control systems," presented at the 2000 Int. Conf. Autom., Robot., Control, Singapore, Dec. 2000.

[66] Y. Q. Chen and K. L. Moore, "Improved path following for an omni-directional vehicle via practical iterative learning control using local symmetrical double-integration," in *Proc. 3rd Asian Control Conf.*, Shanghai, China, Jul. 2000, pp. 1878–1883.

[67] Y. Q. Chen and K. L. Moore, "A practical iterative learning path-following control of an omni-directional vehicle," *Asian J. Control*, vol. 4, no. 1, pp. 90–98, 2002.

[68] Y. Q. Chen, L. L. Tan, K. K. Ooi, Q. Bi, and K. H. Cheong, "Repeatable runout compensation using a learning algorithm with scheduled parameters," U.S. Patent 6, 437, 936, U.S. Pat. Office, Washington, DC, Aug. 20, 2000.

[69] Y.Q. Chen, J.-X. Xu, and M. Sun, "Extracting aerobomb's aerodynamic drag coefficient curve from theodolite data via iterative learning," in *Proc. 14th World Congr. of IFAC*, Beijing, China, 1999, pp. 115–120.

[70] Y. Q. Chen, Z. M. Gong, and C. Y. Wen, "Analysis of a high-order iterative learning control algorithm for uncertain nonlinear systems with state delays," *Automatica*, vol. 34, no. 3, pp. 345–353, 1998.

[71] Y. Q Chen, C. Wen, Z. Gong, and M. Sun, "An iterative learning controller with initial state learning," *IEEE Trans. Autom. Control*, vol. 44, no. 2, pp. 371–376, Feb. 1999.

[72] J. W. Cheng, Y. W. Lin, and F. S. Liao, "Design and analysis of model-based iterative learning control of injection molding process," in *Proc. ANTEC 2003 Annu. Tech. Conf.*, Brookfield Center, CT, May, pp. 556–560.

[73] H. G. Chiacchiarini and P. S. Mandolesi, "Unbalance compensation for active Magnetic bearings using ILC," in *Proc. 2001 IEEE Int. Conf. Control Appl.*, Mexico City, Mexico, Sep., pp. 58–63.

[74] C. J. Chien, "A discrete iterative learning control for a class of nonlinear time-varying systems," *IEEE Trans. Autom. Control*, vol. 43, no. 5, pp. 748–752, May 1998.

[75] C. J. Chien, C. T. Hsu, and C. Y. Yao, "Fuzzy system-based adaptive iterative learning control for nonlinear plants with initial state errors," *IEEE Trans. Fuzzy Syst.*, vol. 12, no. 5, pp. 724–732, Oct. 2004.

[76] C. J. Chien and C. Y. Yao, "Iterative learning of model reference adaptive controller for uncertain nonlinear systems with only output measurement," *Automatica*, vol. 40, no. 5, pp. 855–864, 2004.

[77] C. J. Chien and C. Y. Yao, "An output-based adaptive iterative learning controller for high relative degree uncertain linear systems," *Automatica*, vol. 40, no. 1, pp. 145–153, 2004.

[78] C.-J. Chien, "An output based iterative learning controller for systems with arbitrary relative degree," presented at the 3rd Asian Control Conf., Shanghai, China, 2000.

[79] C.-J. Chien, "A sampled-data iterative learning control using fuzzy network design," *Int. J. Control*, vol. 73, no. 10, pp. 902–913, 2000.

[80] C.-J. Chien and L.-C. Fu, "A neural network based learning controller for robot Manipulators," in *Proc. 39th IEEE Conf. Decision Control*, Sydney, NSW, Dec.2000, pp. 1748–1753.

[81] C.-J. Chien and L.-C. Fu, "An iterative learning control of nonlinear systems using neural network design," *Asian J. Control*, vol. 4, no. 1, pp. 21–29, 2002.

[82] C. J. Chien, "A sampled-data iterative learning control using fuzzy network design," *Int. J. Control*, vol. 73, no. 10, pp. 902–913, 2000.

[83] I. Chin, S. J. Qin, K. S. Lee, and M. Cho, "A two-stage iterative learning control technique combined with real-time feedback for independent disturbance rejection," *Automatica*, vol. 40, no. 11, pp. 1913–1920, 2004.

[84] I. S. Chin, J. Lee, H. Ahn, S. Joo, K. S. Lee, and D. Yang, "Optimal iterative learning control of wafer temperature uniformity in rapid thermal processing," in *Proc. IEEE Int. Symp. Ind. Electron.*, Pusan, Korea, Jun. 2001, pp. 1225–1230.

[85] S. Chin, Kwang S. Lee, and Jay H. Lee, "A unified framework for combined quality and tracking control of batch processes," in *Proc. 14th World Congr. of IFAC*, Beijing, China, 1999, pp. 349–354.

[86] M. Cho, Y. Lee, S. Joo, and K. S. Lee, "Sensor location, identification, and multivariable iterative learning control of an RTP process for maximum uniformity of wafer temperature distribution," in *Proc. 11th IEEE Int. Conf. Adv. Thermal Process. Semicond.*, Sep. 2003, pp. 177–184.

[87] W. Cho, T. F. Edgar, and J. Lee, "Iterative learning dual-mode control of exothermic batch reactors," presented at the 5th Asian Control Conf., Melbourne, Australia, Jul. 2004.

[88] C. H. Choi and G. M. Jeong, "Perfect tracking for maximum-phase nonlinear systems by iterative learning control," *Int. J. Syst. Sci.*, vol. 32, no. 9, pp. 1177–1183, 2001.

[89] C.-H. Choi and T.-J. Jang, "Iterative learning control in feedback systems based on an objective function," *Asian J. Control*, vol. 2, no. 2, pp. 101–110, 2000.

[90] C.-H. Choi and G.-M. Jeong, "Iterative learning control for linear nonminimum-phase systems based on initial state learning," presented at the 3rd Asian Control Conf., Shanghai, China, 2000.

[91] C.-H. Choi, G.-M. Jeong, and T.-J. Jang, "Optimal output tracking for discrete time nonlinear systems," in *Proc. 14th World Congr. IFAC*, Beijing, China, 1999, pp. 1–6.

[92] J. Y. Choi and H. M. Do, "A learning approach of wafer temperature control in a rapid thermal processing system," *IEEE Trans. Semcond. Manufact.*, vol. 14, no. 1, pp. 1–10, Feb. 2001.

[93] J.-Y. Choi, J. Uh, and J. S. Lee, "Iterative learning control of robot manipulator with I-type parameter estimator," in *Proc. 2001 Amer. Control Conf.*, Arlington, VA, Jun. 2001, pp. 646–651.

[94] J. Y. Choi and J. S. Lee, "Adaptive iterative learning control of uncertain robotic systems," *Proc. Inst. Elect. Eng. —Control Theory Appl.*, vol. 147, no. 2, pp. 217–223, Mar. 2000.

[95] J. Y. Choi and H. J. Park, "Use of neural networks in iterative learning control systems," *Int. J. Syst. Sci.*, vol. 31, no. 10, pp. 1227–1239, 2000.

[96] T. W. S. Chow and Y. Fang, "An iterative learning control method for continuous-time systems based on 2-D system theory," *IEEE Trans. Circuits Syst. I, Fundam. Theory Appl.*, vol. 45, no. 6, pp. 683–689, Jun. 1998.

[97] T. W. S. Chow, X. D. Li, and Y. Fang, "A real-time learning control approach for nonlinear continuous-time system using recurrent neural networks," *IEEE Trans. Ind. Electron.*, vol. 47, no. 2, pp. 478–486, Apr. 2000.

[98] B. T. Costic, M. S. de Queiroz, and D. N. Dawson, "A new learning control approach to the active magnetic bearing benchmark system," in *Proc. 2000 Amer. Control Conf.*, Chicago, IL, Jun. 2000, pp. 2639–2643.

[99] B. G. Dijkstra and O. H. Bosgra, "Convergence design considerations of low order Q-ILC for closed loop systems, implemented on a high precision wafer stage," in *Proc. 41st IEEE Conf. Decision Control*, Las Vegas, NV, Dec. 2002, pp. 2494–2499.

[100] B. G. Dijkstra and O. H. Bosgra, "Extrapolation of optimal lifted system ILC solution, with application to a waferstage," in *Proc. 2002 Amer. Control Conf.*, Anchorage, AK, May, pp. 2595–2600.

[101] B. G. Dijkstra and O. H. Bosgra, "Noise suppression in buffer-state iterative learning control, applied to a high precision wafer stage," in *Proc. 2002 Int. Conf. Control Appl.*, Glasgow, U.K., Sep., pp. 998–1003.

[102] B. G. Dijkstra and O. H. Bosgra, "Exploiting iterative learning control for input shaping, with application to a wafer stage," in *Proc. 2003 Amer. Control Conf.*, Denver, CO, Jun. 2003, pp. 4811–4815.

[103] B. Dijkstra, "Iterative learning control with applications to a wafer-stage," Ph.D. dissertation, Delft Univ. Technol., Delft, Netherlands, 2004.

[104] T.-Y. Doh and J.-H. Moon, "Feedback-based iterative learning control for uncertain linear mimo systems," presented at the 5th Asian Control Conf., Melbourne, Australia, Jul. 2004.

[105] T. Y. Doh and J. H. Moon, "An iterative learning control for uncertain systems using structured singular value," *J. Dyn. Syst. Meas. Control. Trans. ASME*, vol. 121, no. 4, pp. 660–667, 1999.

[106] T. Y. Doh, J. H. Moon, K. B. Jin, and M. J. Chung, "Robust iterative learning control with current feedback for uncertain linear systems," *Int. J. Syst. Sci.*, vol. 30, no. 1, pp. 39–47, 1999.

[107] H. F. Dou, K. K. Tan, T. H. Lee, and Z. Y. Zhou, "Iterative learning feedback control of human limbs via functional electrical stimulation," *Control Eng. Pract.*, vol. 7, no. 3, pp. 315–325, 1999.

[108] B. J. Driessen and N. Sadegh, "Convergence theory for multi-input discrete-time iterative learning control with Coulomb friction, continuous outputs, and input bounds," in *Proc. IEEE SoutheastCon*, Columbia, SC, Apr. 2002, pp. 287–293.

[109] B. J. Driessen and N. Sadegh, "Global convergence for two-pulse rest-to-rest learning for single-degree-of-freedom systems with stick-slip Coulomb friction," in *Proc. 41st IEEE Conf. Decision Control*, Las Vegas, NV, Dec. 2002, pp. 3338–3343.

[110] B. J. Driessen and N. Sadegh, "Multi-input square iterative learning control with bounded inputs," *J. Dyn. Syst. Meas. Control, Trans. ASME*, vol. 124, no. 4, pp. 582–584, 2002.

[111] B. J. Driessen and N. Sadegh, "Convergence theory for multi-input discrete-time iterative learning control with Coulomb friction, continuous outputs, and input bounds," *Int. J. Adapt. Control Singal Process.*, vol. 18, no. 5, pp. 457–471, 2004.

[112] M. Dymkov, I. Gaishun, K. Galkowski, E. Rogers, and D. H. Owens, "A Volterra operator approach to the stability analysis of a class of 2D linear systems," presented at the 2001 Eur. Control Conf., Seminário de Vilar, Porto, Portugal, Sep.

[113] M. Dymkov, I. Gaishun, E. Rogers, K. Galkowski, and D. H. Owens, "On the observability properties of a class of 2D discrete linear systems," in *Proc. 40th IEEE Conf. Decision Control*, Orlando, FL, Dec. 2000, pp. 3625–3630.

[114] M. Dymkov, I. Gaishun, E. Rogers, K. Galkowski, and D. H. Owens, "z-transform and volterra-operator based approaches to controllability and observability analysis for discrete linear repetitive processes," *Multidimensional Syst. Signal Process.*, vol. 14, no. 4, pp. 365–395, 2003.

[115] H. S. M. Beigi (Ed.), Special Issue on learning repetitive control. *Intell. Autom. Soft Comput.*, vol. 8, no. 2, 2002.

[116] J. B. Edwards, "stability problems in the control of linear multipass processes," *Proc. Inst. Elect. Eng.*, vol. 121, no. 11, pp. 1425–1431, 1974.

[117] H. Elci, R. W. Longman, M. Q. Phan, J. N. Juang, and R. Ugoletti, "Simple learning control made practical by zero-phase filtering: Applications to robotics," *IEEE Trans. Circuits Syst. I, Fundam. Theory Appl.*, vol. 49, no. 6, pp. 753–767, Jun. 2002.

[118] Y. Fang and T. W. S. Chow, "Iterative learning control of linear discrete-time multivariable systems," *Automatica*, vol. 34, no. 11, pp. 1459–1462, 1998.

[119] Y. Fang and T. W. S. Chow, "2-D analysis for iterative learning controller for discrete-time systems with variable initial conditions," *IEEE Trans. Circuits Syst. I, Fundam. Theory Appl.*, vol. 50, no. 5, pp. 722–727, May 2003.

[120] Y. Fang and T. W. S. Chow, "Counterexample to iterative learning control of linear discrete-time multivariable systems—Author's reply," *Automatica*, vol. 36, no. 2, pp. 329–329, 2000.

[121] Y. Fang, Y. C. Soh, and G. G. Feng, "Convergence analysis of iterative learning control with uncertain initial conditions," in *Proc. 4th World Congr. Intell. Control Autom.*, Shanghai, China, Jun. 2002, pp. 960–963.

[122] C. T. Freeman, P. L. Lewin, and E. Rogers, "Experimental evaluation of simple structure ILC algorithms for non-minimum phase plants," in *Proc. 3rd IFAC Symp. Mechatronic Syst.*, Sydney, Australia, 2004, pp. 205–210.

[123] C. T. Freeman, P. L. Lewin, and E. Rogers, "Phase-lead based iterative learning control implemented experimentally on a non-minimum phase plant," in *Proc. 3rd IFAC Symp. Mechatronic Syst.*, Sydney, Australia, 2004, pp. 193–198.

[124] M. French, G. Munde, E. Rogers, and D. H. Owens, "Recent developments in adaptive iterative learning control," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec.1999, pp. 264–269.

[125] M. French and E. Rogers, "Nonlinear iterative learning by an adaptive Lyapunov technique," in *Proc. 37th IEEE Conf. Decision Control*, Tampa, FL, Dec.1998, pp. 175–180.

[126] M. French and E. Rogers, "Non-linear iterative learing by an adaptive Lyapunov technique," *Int. J. Control*, vol. 73, no. 10, pp. 840–850, 2000.

[127] M. French and E. Rogers, "Nonlinear iterative learning by an adaptive Lyapunov technique," in *Proc. IEEE Semin. Learn. Syst. Control*, May 2000, pp. 9/1–9/2.

[128] M. French, E. Rogers, H. Wibowo, and D. H. Owens, "A 2D systems approach to iterative learning control based on nonlinear adaptive control techniques," in *Proc. 2001 IEEE Int. Symp. Circuits Syst.*, Sydney, Australia, May, pp. 429–432.

[129] J. A. Frueh and M. Q. Phan, "Linear quadratic optimal learning control (LQL)," in *Proc. 37th IEEE Conf. Decision Control*, Tampa, FL, Dec.1998, pp. 678–683.

[130] J. A. Frueh and M. Q. Phan, "Linear quadratic optimal learning control (LQL)," *Int. J. Control*, vol. 73, no. 10, pp. 832–839, 2000.

[131] J. A. Frueh, "Iterative learning control with basis functions" Ph.D. dissertation, Princeton Univ., Princeton, NJ, 2000.

[132] K. Fujimoto, "Optimal control of Hamiltonian systems via iterative learning," in *Proc. SICE 2003 Annu. Conf.*, Aug., pp. 2617–2622.

[133] K. Fujimoto, H. Kakiuchi, and T. Sugie, "Iterative learning control of Hamiltonian systems," in *Proc. 41st IEEE Conf. Decision Control*, Las Vegas, NV, Dec. 2002, pp. 3344–3349.

[134] K. Fujimoto and T. Sugie, "Iterative learning control of Hamiltonian systems based on self-adjoint structure-I/O based optimal control," in *Proc. 41st SICE Annu. Conf.*, Aug. 2002, pp. 2573–578.

[135] K. Fujimoto and T. Sugie, "Iterative learning control of Hamiltonian systems: I/O based optimal control approach," *IEEE Trans. Autom. Control*, vol. 48, no. 10, pp. 1756–1761, Oct. 2003.

[136] K. Fujimoto and T. Sugie, "On adjoints of Hamiltonian systems," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.

[137] K. Furuta and M. Yamakita, "The design of a learning control system for multivariable systems," in *Proc. 30th Conf. Decision Control*, Philadelphia, PA, 1987, pp. 371–376.

[138] K. Galkowski, J. Lam, E. Rogers, S. Xu, B. Sulikowski, W. Paszke, and D. H. Owens, "LMI based stability analysis and robust controller design for discrete linear repetitive processes," *Int. J. Robust Nonlinear Control*, vol. 13, no. 13, pp. 1195–1211, 2003.

[139] K. Galkowski, W. Paszke, E. Rogers, and D. H. Owens, "Stabilization and robust control of metal rolling modeled as a 2D linear system," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.

[140] K. Galkowski, W. Paszke, B. Sulikowski, E. Rogers, and D. H. Owens, "LMI based stability analysis and controller design for a class of 2D continuous-discrete linear systems," in *Proc. 2002 Amer. Control Conf.*, Anchorage, AK, May, pp. 29–34.

[141] K. Galkowski, E. Rogers, A. Gramacki, J. Gramacki, and D. H. Owens, "Stability and dynamic boundary condition decoupling analysis for a class of 2-D discrete linear systems," *IEEE Proc. —Circuits Devices Syst.*, Jun. 2001, vol. 148, no. 3, pp. 126–134.

[142] K. Galkowski, E. Rogers, and D. H. Owens, "New 2D models and a transition matrix far discrete linear repetitive processes," *Int. J. Control*, vol. 72, no. 15, pp. 1365–1380, 1999.

[143] K. Galkowski, E. Rogers, J. Wood, S. E. Benton, and D. H. Owens, "One-dimensional equivalent model and related approaches to the analysis of discrete nonunit memory linear repetitive processes," *Circuits Syst. Signal Process.*, vol. 21, no. 6, pp. 525–534, 2002.

[144] K. Galkowski, E. Rogers, S. Xu, J. Lam, and D. H. Owens, "LMIs—A fundamental tool in analysis and controller design for discrete linear repetitive processes," *IEEE Trans. Circuits Syst. I, Fundam. Theory Appl.*, vol. 49, no. 6, pp. 768–778, Jun. 2002.

[145] F. R. Gao, Y. Yang, and C. Shao, "Robust iterative learning control with applications to injection molding process," *Chem. Eng. Sci.*, vol. 56, no. 24, pp. 7025–7034, 2002.

[146] S. S. Garimella and K. Srinivasan, "Application of iterative learning control to coil-to-coil control in rolling," *IEEE Trans. Control Syst. Technol.*, vol. 6, no. 2, pp. 281–293, Mar. 1998.

[147] J. Ghosh and B. Paden, "Iterative learning control for nonlinear nonminimum phase plants with input disturbances," in *Proc. 1999 Amer. Control Conf.*, San Diego, CA, Jun.1999, pp. 2584–2589.

[148] J. Ghosh and B. Paden, "Pseudo-inverse based iterative learning control for nonlinear plants with disturbances," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec.1999, pp. 5206–5212.

[149] J. Ghosh and B. Paden, "Pseudo-inverse based iterative learning control for plants with unmodelled dynamics," in *Proc. 2000 Amer. Control Conf.*, Chicago, IL, Jun. 2000, pp. 472–476.

[150] J. Ghosh and B. Paden, "Iterative learning control for nonlinear nonminimum phase plants," *J. Dyn. Syst. Meas. Control—Trans. ASME*, vol. 123, no. 1, pp. 21–30, 2001.

[151] J. Ghosh and B. Paden, "A pseudoinverse-based iterative learning control," *IEEE Trans. Autom. Control*, vol. 45, no. 5, pp. 831–837, May 2002.

[152] J. Ghosh, "Tracking of periodic trajectories in nonlinear plants" Ph.D. dissertation, Univ. California, Santa Barbara, CA, 2000.

[153] P. B. Goldsmith, "The equivalence of LTI iterative learning control and feedback control," in *Proc. 2000 IEEE Int. Conf. Syst., Man, Cybern.*, Nashville, TN, Oct., pp. 3443–3448.

[154] P. B. Goldsmith, "The fallacy of causal iterative learning control," in *Proc. 2001 Amer. Control Conf.*, Arlington, VA, Jun., pp. 4475–4480.

[155] P. B. Goldsmith, "On the equivalence of causal LTI iterative learning control and feedback control," *Automatica*, vol. 38, no. 4, pp. 703–708, 2002.

[156] P. B. Goldsmith, "Author's reply to comments on 'On the equivalence of causal LTI iterative learning control and feedback control'," *Automatica*, vol. 40, no. 5, pp. 899–900, 2004.

[157] Peter B. Goldsmith, "stability, convergence, and feedback equivalence of LTI iterative learning control," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.

[158] S. Gopinath and I. N. Kar, "Iterative learning control scheme for manipulators including actuator dynamics," *Mech. Mach. Theory*, vol. 39, no. 12, pp. 1367–1384, 2004.

[159] D. Gorinevsky, "Distributed system loopshaping design of iterative control for batch processes," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec.1999, pp. 245–250.

[160] Dimitry M. Gorinevsky, "Iterative learning update for batch mode processing," U.S. Patent 6, 647, 354, U.S. Pat. Office, Washington, DC, Nov. 11, 2003.

[161] J. Gramacki, A. Gramacki, K. Galkowski, E. Rogers, and D. H. Owens, "MATLAB based tools for 2D linear systems with application to iterative learning control schemes," in *Proc. 1999 IEEE Int. Symp. Comput. Aided Control Syst. Design*, Kohala Coast, HI, Aug., pp. 410–415.

[162] M. Grundelius, "Iterative optimal control of liquid slosh in an industrial packaging Machine," in *Proc. 39th IEEE Conf. Decision Control*, 2000, pp. 3427–3432.

[163] M. Grundelius and B. Bernhardsson, "Constrained iterative learning control of liquid slosh in an industrial packaging Machine," in *Proc. 39th IEEE Conf. Decision Control*, Sydney, Australia, Dec. 2000, pp. 4544–4549.

[164] S. Gunnarsson and M. Norrlöf, "Some aspects of an optimization approach to iterative learning control," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec.1999, pp. 1581–1586.

[165] K. Hamamoto and T. Sugie, "An iterative learning control algorithm within prescribed input-output subspace," *Automatica*, vol. 37, no. 11, pp. 1803–1809, 2001.

[166] K. Hamamoto and T. Sugie, "Iterative learning control for robot manipulators using the finite dimensional input subspace," in *Proc. 40th IEEE Conf. Decision Control*, Orlando, FL, Dec. 2001, pp. 4926–4931.

[167] K. Hamamoto and T. Sugie, "Iterative learning control for robot manipulators using the finite dimensional input subspace," *IEEE Trans. Robot. Autom.*, vol. 18, no. 4, pp. 632–635, Aug. 2002.

[168] Kenichi Hamamoto and Toshiharu Sugie, "An iterative learning control algorithm within prescribed input-output subspace," in *Proc. 14th World Congr. IFAC*, Beijing, China, 1999, pp. 501–506.

[169] J. Hätönen, K. L. Moore, and D. H. Owens, "An algebraic approach to iterative learning control," in *Proc. 2002 IEEE Int. Symp. Intell. Control*,, pp. 37–42.

[170] J. Hätönen and D. H. Owens, "Convex modifications to an iterative learning control law," *Automatica*, vol. 40, no. 7, pp. 1213–1220, 2004.

[171] J. Hätönen, D. H. Owens, K. Feng, and V. E. Hatzikos, "Positivity in repetitive control and iterative learning control," presented at the 5th Int. Conf. Digital Signal Process. Appl., Moscow, Russia, 2003.

[172] J. J. Hätönen, K. Feng, and D. H. Owens, "New connections between positivity and parameter-Optimal iterative learning control," in *Proc. 2003 IEEE Int. Symp. Intell. Control*, Houston, TX, Oct., pp. 69–74.

[173] J. J. Hätönen, T. J. Harte, D. H. Owens, J. D. Ratcliffe, P. L. Lewin, and E. Rogers, "A new robust iterative learning control algorithm for application on a gantry robot," in *Proc. IEEE Conf. Emerging Technol. Factory Autom.*, 2003, pp. 305–312.

[174] J. J. Hätönen, T. J. Harte, D. H. Owens, J. D. Ratcliffe, P. L. Lewin, and E. Rogers, "Discrete-time Arimoto ILC-algorithm revisited," in *Proc. IFAC Workshop Adaption Learning Control Signal Process. IFAC Workshop Periodic Control Syst.*, Yokohama, Japan, 2004, pp. 541–546.

[175] J. J. Hätönen, D. H. Owens, and K. L. Moore, "An algebraic approach to iterative learning control," *Int. J. Control*, vol. 77, no. 1, pp. 45–54, 2004.

[176] Jari Hätönen, "Issues of algebra and optimality in iterative learning control" Ph.D. dissertation, Univ. of Oulu, Oulu, Finland, 2004.

[177] V. Hatzikos, J. Hätönen, and D. H. Owens, "Genetic algorithms in norm-optimal linear and non-linear iterative learning control," *Int. J. Control*, vol. 77, no. 2, pp. 188–197, 2004.

[178] V. Hatzikos and D. H. Owens, "A genetic algorithm based optimisation method for iterative learning control systems," in *Proc. 3rd Int. Workshop Robot Motion Control*, Nov. 2002, pp. 423–428.

[179] V. E. Hatzikos, J. Hätönen, T. Harte, and D. H. Owens, "Robust analysis of a genetic algorithm based optimization method for real-time iterative learning control applications," in *Proc. IEEE Conf. Emerging Technol. Factory Autom. 2003*, Sep. 2003, pp. 396–401.

[180] V. E. Hatzikos, J. Hätönen, and D. H. Owens, "Basis functions and genetic algorithms in nonlinear norm-optimal iterative learning control," presented at the IFAC Int. Conf. Intell. Control Syst. Signal Process., Algarve, Portugal, Apr. 2003.

[181] V. E. Hatzikos and D. H. Owens, "A genetic algorithm based optimisation method for iterative learning control systems," presented at the ROMOCO2002 3rd Workshop Robot Motion Control, Poznan, Poland, Nov.

[182] V. E. Hatzikos, D. H. Owens, and J. Hätönen, "An evolutionary based optimisation method for nonlinear iterative learning control systems," in *Proc. 2003 Amer. Control Conf.*, Denver, CO, Jun., pp. 3638–3643.

[183] H. Havlicsek and A. Alleyne, "Nonlinear control of an electrohydraulic injection molding machine via iterative adaptive learning," *IEEE-ASME Trans. Mechatron.*, vol. 4, no. 3, pp. 312–323, Sep. 1999.

[184] H. Hengen, S. Hillenbrand, and M. Pandit, "Algorithms for iterative learning control of nonlinear plants employing time-variant system descriptions," in *Proc. 2000 IEEE Int. Conf. Control Appl.*, Anchorage, AK, Sep., pp. 570–575.

[185] L. Hideg, "Design of a static neural element in an iterative learning control scheme," in *Proc. 37th IEEE Conf. Decision Control*, Tampa, FL, Dec.1998, pp. 690–694.

[186] S. Hillenbrand and M. Pandit, "A discrete-time iterative learning control law with exponential rate of convergence," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec. 1999, pp. 1575–1580.

[187] S. Hillenbrand and M. Pandit, "An iterative learning controller with reduced sampling rate for plants with variations of initial states," *Int. J. Control*, vol. 73, no. 10, pp. 882–889, 2000.

[188] K. J. G. Hinnen, R. Fraanje, and M. Verhaegen, "The application of initial state correction in iterative learning control and the experimental validation on a piezoelectric tube scanner," in *Proc. Inst. Mech. Eng. Part I J. Syst. Control Eng.*, vol. 218, no. 16, pp. 503–511, 2004.

[189] W. HoffMann, K. Peterson, and A. G. Stefanopoulou, "Iterative learning control for soft landing of electromechanical valve actuator in camless engines," *IEEE Trans. Control Syst. Technol.*, vol. 11, no. 2, pp. 174–184, Mar. 2003.

[190] W. HoffMann and A. G. Stefanopoulou, "Iterative learning control of electromechanical camless valve actuator," in *Proc. 2001 Amer. Control Conf.*, Arlington, VA, Jun., pp. 2860–2866.

[191] H. Holm, H. Bach, M. V. Hansen, and D. Franke, "Planning of finite element modelled welding control variable trajectories by PI-controllers and by iterative learning," presented at the 6th Int. Conf. Trends Welding Res., Pine Mountain, GA, Apr. 2002.

[192] Zhongsheng Hou and Jian-Xin Xu, "Freeway traffic density control using iterative learning control approach," in *Proc. 2003 IEEE Intell. Transp. Syst.*, pp. 1081–1086

[193] Chun-Te Hsu, Chiang-Ju Chien, and Chia-Yu Yao, "A new algorithm of adaptive iterative learning control for uncertain robotic systems," in *Proc. IEEE Int. Conf. Robot. Autom.*, Sep. 2003, pp. 4130–4135.

[194] Ai-Ping Hu and and Nader Sadegh, "Non-collocated control of a flexible-link manipulator tip using a multirate repetitive learning controller," presented at the 3rd Mechatronics Forum Int. Conf., Atlanta, GA, Sep. 2000.

[195] M. Hu, H. J. Du, S. F. Ling, Z. Y. Zhou, and Y. Li, "Motion control of an electrostrictive actuator," *Mechatronics*, vol. 14, no. 2, pp. 153–161, 2004.

[196] M. Hu, Z. Y. Zhou, Y Li, and H. J. Du, "Development of a linear electrostrictive servo motor," *Precision Eng. J. Int. Societies Precision Eng. Nanotechnol.*, vol. 25, no. 4, pp. 316–320, 2001.

[197] Q. P. Hu, J. X. Xu, and T. H. Lee, "Iterative learning control design for Smith predictor," *Syst. Control Lett.*, vol. 44, no. 3, pp. 201–210, 2001.

[198] S. N. Huang and S. Y. Lim, "Predictive iterative learning control," *Intell. Autom. Soft Comput.*, vol. 9, no. 2, pp. 103–112, 2003.

[199] S. N. Huang, K. K. Tan, and T. H. Lee, "Iterative learning algorithm for linear time-varying with a quadratic criterion systems," in *Proc. Inst. Mech. Eng. Part I J. Syst. Control Eng.*, 2002, vol. 216, no. I3, pp. 309–316.

[200] W. Huang, "Tracking control of nonlinear mechanical systems using Fourier series based learning control," Ph.D. dissertation, Hong Kong Univ. Sci. Tech., Hong Kong, China, 1999.

[201] W. Huang, L. Cai, and X. Tang, "Adaptive repetitive output feedback control for friction and backlash compensation of a positioning table," in *Proc. 37th IEEE Conf. Decision Control*, Tampa, FL, Dec.1998, pp. 1250–1251.

[202] Y. C. Huang, M. Chan, Y. P. Hsin, and C. C. Ko, "Use of PID and iterative learning controls on improving intra-oral hydraulic loading system of dental implants," *JSME Int. J. Series C Mech. Syst. Mach. Elements Manuf.*, vol. 46, no. 4, pp. 1449–1455, 2003.

[203] Y.-C. Huang, M. Chan, Y.-P. Hsin, and C.-C. Ko, "Use of iterative learning control on improving intra-oral hydraulic loading system of dental implants," in *Proc. 2003 IEEE Int. Symp. Intell. Control*, Houston, TX, Oct., pp. 63–68.

[204] S. Islam and A. Tayebi, "New adaptive iterative learning control (AILC) for uncertain robot manipulators," in *Proc. Can. Conf. Elect. Comput. Eng.*, May 2004, vol. 3, pp. 1645–1651.

[205] G. M. Jeong and C. H. Choi, "Iterative learning control for linear discrete time nonminimum phase systems," *Automatica*, vol. 38, no. 2, pp. 287–291, 2002.

[206] G.-M. Jeong and C.-H. Choi, "Iterative learning control with advanced output data," in *Proc. 3rd Asian Control Conf.*, Shanghai, China, 2000, pp. 1895–1900.

[207] G.-M. Jeong and C.-H. Choi, "Iterative learning control with advanced output data for nonminimum phase systems," in *Proc. 2001 Amer. Control Conf.*, Arlington, VA, Jun., pp. 890–895.

[208] G.-M. Jeong and C.-H. Choi, "Iterative learning control with advanced output data," *Asian J. Control*, vol. 4, no. 1, pp. 30–37, 2002.

[209] P. Jiang and R. Unbehauen, "Iterative learning neural network control for nonlinear system trajectory tracking," *Neurocomputing*, vol. 48, pp. 141–153, 2002.

[210] P. Jiang and R. Unbehauen, "Robot visual servoing with iterative learning control," *IEEE Trans. Syst. Man Cybern. A, Syst., Humans*, vol. 32, no. 2, pp. 281–287, 2002.

[211] P. Jiang, P. Y. Woo, and R. Unbehauen, "Iterative learning control for manipulator trajectory tracking without any control singularity," *Robotica*, vol. 20, no. 2, pp. 149–158, 2002.

[212] P. Jiang, H.-T. Chen, and Y.-J. Wang, "Iterative learning control for glass cutting robot," in *Proc. 14th World Congr. IFAC*, Beijing, China, 1999, pp. 263–268.

[213] P. Jiang and H. Chen, "Robot teach by showing with iterative learning control," presented at the 3rd Asian Control Conf., Shanghai, China, 2000.

[214] P. Jiang and Y. Q. Chen, "Repetitive robot visual servoing via segmented trained neural network controller," in *Proc. 2001 IEEE Int. Symp. Comput. Intell. Robot. Autom.*, Jul. 29–Aug. 1, pp. 260–265.

[215] P. Jiang and Y. Q. Chen, "Singularity-free neural network controller with iterative training," in *Proc. 2002 IEEE Int. Symp. Intell. Control*, Vancouver, BC, Canada, Oct., pp. 31–36.

[216] P. Jiang and R. Unbehauen, "An iterative learning control scheme with deadzone," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec. 1999, pp. 3816–3817.

[217] P. Jiang, R. Unbehauen, and P.-Y. Woo, "Singularity-free indirect iterative learning control," in *Proc. 40th IEEE Conf. Decision Control*, Orlando, FL, Dec. 2001, pp. 4903–4908.

[218] D. M. Joffe and D. C. Panek, Jr, "DTMF signaling on four-wire switched 56 KBPS lines," U.S. Patent 5, 748, 637, U.S. Pat. Office, Washington, DC, May 1998.

[219] S. Kawamura, N. Fukao, and H. Ichii, "Planning and control of robot motion based on time-scale transformation and iterative learning control," in *Proc. 9th Int. Symp. Robot. Res.*, Snowbird, UT, Oct. 1999, pp. 213–220.

[220] S. Kawamura and N. Sakagami, "Analysis on dynamics of underwater robot manipulators based on iterative learning control and time-scale transformation," in *Proc. IEEE Int. Conf. Robot. Autom.*, Washington, DC, May 2002, pp. 1088–1094.

[221] W. C. Kim, I. S. Chin, K. S. Lee, and J. H. Choi, "Analysis and reduced-order design of quadratic criterion-based iterative learning control using singular value decomposition," *Comput. Chem. Eng.*, vol. 24, no. 8, pp. 1815–1819, 2000.

[222] Y. H. Kim and I. J. Ha, "Asymptotic state tracking in a class of nonlinear systems via learning-based inversion," *IEEE Trans. Autom. Control*, vol. 45, no. 11, pp. 2011–2027, Nov. 2001.

[223] Y.-T. Kim, H. Lee, H.-S. Noh, and Z. Bien, "Robust higher-order iterative learning control for a class of nonlinear discrete-time systems," in *Proc. IEEE Int. Conf. Syst., Man Cybern.*, Oct. 2003, pp. 2219–2224.

[224] K. Kinoshita, T. Sogo, and N. Adachi, "Adjoint-type iterative learning control for a single-link flexible arm," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.

[225] K. Kinosita, T. Sogo, and N. Adachi, "Iterative learning control using adjoint systems and stable inversion," *Asian J. Control*, vol. 4, no. 1, pp. 60–67, 2002.

[226] K. Kinosita, T. Sogo, and N. Adachi, "Iterative learning control using noncausal updating for non-minimum phase systems," presented at the 3rd Asian Control Conf., Shanghai, China, 2000.

[227] J. E. Kurek, "Stabilities of 2-D linear discrete-time systems," in *Proc. 9th IFAC World Congress*, Budapest, Hungary, 1984, pp. 191–195.

[228] J. E. Kurek and M. B. Zaremba, "Iterative learning control synthesis based on 2-D sytem theory," *IEEE Trans. Autom. Control*, vol. 38, no. 1, pp. 121–125, Jan. 1993.

[229] J. E. Kurek, "Counterexample to iterative learning control of linear discrete-time multivariable systems," *Automatica*, vol. 36, no. 2, pp. 327–328, 2000.

[230] S. I. Kwon, A. Regan, and Y. M. Wang, "SNS superconducting RF cavity modeling-iterative learning control," *Nucl. Instrum. Methods Phys. Res. S. A—Acceler. Spectrom. Decte. Assoc. Equip.*, vol. 482, no. 1–2, pp. 12–31, 2002.

[231] B. H. Lam, S. K. Panda, and J. X. Xu, "Reduction of periodic speed ripples in PM synchronous motors using iterative learning control," in *Proc. 26th Annu. Conf. IEEE Ind. Electron. Soc.*, Nagoya, Japan, 2000, pp. 1406–1411.

[232] B. H. Lam, S. K. Panda, J. X. Xu, and K. W. Lim, "Torque ripple minimization in PM synchronous motor using iterative learning control," in *Proc. 25th Annu. Conf. IEEE Ind. Electron. Soc.*, San Jose, CA, Nov. 29–Dec. 31999, pp. 1458–1463.

[233] H. S. Lee and Z. Bien, "Design issues on robustness and convergence of iterative learning controller," *Intell. Autom. Soft Comput.*, vol. 8, no. 2, pp. 95–106, 2002.

[234] J. H. Lee, S. Natarajan, and K. S. Lee, "A model-based predictive control approach to repetitive control of continuous processes with periodic operations," *J. Process Control*, vol. 11, no. 2, pp. 195–207, 2001.

[235] J. H. Lee, K. S. Lee, and W. C. Kim, "Model-based iterative learning control with a quadratic criterion for time-varying linear systems," *Automatica*, vol. 36, no. 5, pp. 641–657, 2000.

[236] J. Lee, I. Chin, K. S. Lee, and J. Choi, "Temperature uniformity control in rapid thermal processing using an iterative learning control technique," in *Proc. 3rd Asian Control Conf.*, Shanghai, China, 2000, pp. 419–423.

[237] K. S. Lee, J. Lee, I. Chin, J. Choi, and J. H. Lee, "Control of wafer temperature uniformity in rapid thermal processing using an optimal iterative learning control technique," *Ind. Eng. Chem. Res.*, vol. 40, no. 7, pp. 1661–1672, 2001.

[238] K. S. Lee and J. H. Lee, "Iterative learning control-based batch process control technique for integrated control of end product properties and transient profiles of process variables," *J. Process Control*, vol. 13, no. 7, pp. 607–621, 2003.

[239] K. S. Lee and J. H. Lee, "Convergence of constrained model-based predictive control for batch processes," *IEEE Trans. Autom. Control*, vol. 45, no. 10, pp. 1928–1932, Oct. 2000.

[240] K. S. Lee, H. Ahn, I. S. Chin, J. H. Lee, and D. R. Yang, "Optimal iterative learning control of wafer temperature uniformity in rapid thermal processing," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.

[241] S. C. Lee, R. W. Longman, and M. Q. Phan, "Direct model reference learning and repetitive control," *Intell. Autom. Soft Comput.*, vol. 8, no. 2, pp. 143–161, 2002.

[242] T. H. Lee, K. K. Tan, S. N. Huang, and H. F. Dou, "Intelligent control of precision linear actuators," *Eng. Appl. Artif. Intell.*, vol. 13, no. 6, pp. 671–684, 2001.

[243] T. H. Lee, K. K. Tan, S. Y. Lim, and H. F. Dou, "Iterative learning control of permanent magnet linear motor with relay automatic tuning," *Mechatronics*, vol. 10, no. 1/2, pp. 169–190, 2000.

[244] P. A. Levoci and R. W. Longman, "Frequency domain prediction of final error due to noise in learning and repetitive control," *Adv. Astronaut. Sci.*, vol. 112, no. 2, pp. 1341–1359, 2002.

[245] P. A. LeVoci and R. W. Longman, "Intersample error in discrete time learning and repetitive control," in *AIAA/AAS Astrodynamics Spec. Conf. Exhibit*, Providence, RI, 16–18 Aug. 2004.

[246] P. LeVoci, "Prediction final error level in leraning and repetitive control," Ph.D. dissertation, Columbia Univ., New York, 2004.

[247] S. C. Li, X. H. Xu, and L. Ping, "Feedback-assisted iterative learning control for batch polymerization reactor," *Adv. Neural Netw.-ISNN 2004, Part 2 Lecture Notes Comput. Sci.*, vol. 3174, Springer-Verlag, pp. 181–187, Aug..

[248] S. Li, X. Xu, and P. Li, "Frequency domain analysis for feedback-assisted iterative learning control," in *Proc. Int. Conf. Inf. Acquisition*, Hefei, China, Jun. 2004, pp. 1–4.

[249] W. Li, P. maisser, and H. Enge, "Self-learning control applied to vibration control of a rotating spindle by piezopusher bearings," *Proc. Inst. Mech. Eng. Part I—J. Syst. Control Eng.*, vol. 218, no. 13, pp. 185–196, 2004.

[250] Z. G. Li, C. W. Wen, Y. C. Soh, and Y. Q. Chen, "Iterative learning control of linear time varying uncertain systems," in *Proc. 3rd Asian Control Conf.*, Shanghai, China, 2000, pp. 1890–1894.

[251] D. Liu, L.-C. Fu, S.-H. Hsu, and T.-K. Kuo, "Analysis on an on-line iterative correction control law for visual tracking," in *Proc. 3rd Asian Control Conf.*, Singapore, Sep. 2002, pp. 2130–2133.

[252] D. Liu, A. Konno, and M. Uchiyama, "Flexible manipulator trajectory learning control with input preshaping method," in *Proc. 38th Annu. Conf. Proc. SICE Annu.*, Morioka, Japan, Jul.1999, pp. 967–972.

[253] H. Liu and D. Wang, "Convergence of CMAC network learning control for a class of nonlinear dynamic system," in *Proc. 1999 IEEE Int. Symp. Intell. Control/Intell. Syst. Semiotics*, Cambridge, MA, Sep.1999, pp. 108–113.

[254] C. P. Lo, "Departure angle based and frequency based compensator design in learning and repetitive control," Ph.D. dissertation, Columbia University, New York, 2004.

[255] R. W. Longaman, Y.-T. Peng, T. Kwon, H. Lus, R. Betti, and J.-N. Juang, "Adaptive inverse iterative learning control," in *Proc. Spaceflight Mech. 2003*, San Diego, CA, Feb., pp. 115–134.

[256] R. W. Longman and Y. C. Huang, "The phenomenon of apparent convergence followed by divergence in learning and repetitive control," *Intell. Autom. Soft Comput.*, vol. 8, no. 2, pp. 107–128, 2002.

[257] R. W. Longman, Y. T. Peng, T. Kwon, H. Lus, R. Betti, and J. N. Juang, "Adaptive inverse iterative learning control," *Adv. Astronaut. Sci.*, vol. 114, pp. 115–134, 2003.

[258] R. W. Longman and S. L. Wirkander, "Automated tuning concepts for iterative learning and repetitive control laws," in *Proc. 37th IEEE Conf. Decision Control*, Tampa, FL, Dec.1998, pp. 192–198.

[259] R. W. Longman, "Iterative learning control and repetitive control for engineering practice," *Int. J. Control*, vol. 73, no. 10, pp. 930–954, 2000.

[260] Y. Lv and Y. Wei, "Study on open-loop precision positioning control of a micropositioning platform using a piezoelectric actuator," in *Proc. 5th World Congr. Intell. Control Autom.*, Hangzhou, China, Jun. 2004, pp. 1255–1259.

[261] L. Ma, "Vison-based measurements for dynamic systems and control," Ph.D. dissertation, Utah State Univ., Logan, Utah, 2004.

[262] A. Madady, "Self tuning iterative learning control systems," presented at the 5th Asian Control Conf., Melbourne, Australia, Jul. 2004.

[263] K. Mainali, S. K. Panda, J. X. Xu, and T. Senjyu, "Position tracking performance enhancement of linear ultrasonic motor using iterative learning control," in *Proc. IEEE 35th Annu. Power Electron. Spec. Conf.*, Aachen, Germany, Jun. 2004, pp. 4844–4849.

[264] K. Mainali, S. K. Panda, J. X. Xu, and T. Senjyu, "Repetitive position tracking performance enhancement of linear ultrasonic motor with sliding mode-cum-iterative learning control," in *Proc. IEEE Int. Conf. Mechatronics, 2004*, Jun. 2004, pp. 352–357.

[265] O. Markusson, H. Hjalmarsson, and M. Norrlöf, "Iterative learning control of nonlinear non-minimum phase systems and its application to system and model inversion," in *Proc. 40th IEEE Conf. Decision Control*, Orlando, FL, Dec. 2001, pp. 4481–4482.

[266] O. Markusson, "Model and system inversion with applications in nonlinear system identification and control" Ph.D. dissertation, Kungliga Tekniska Hogskolan, Sweden, 2002.

[267] O. Markusson, H. Hjalmarsson, and M. Norrlöf, "A general framework for iterative learning control," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.

[268] M. Matsushima, T. Hashimoto, and F. Miyazaki, "Learning to the robot table tennis task-ball control & rally with a human," in *Proc. IEEE Int. Conf. Syst., Man Cybern.*, Oct. 2003, pp. 2962–2969.

[269] M. Mezghani, M. V. Lelann, G. Roux, M. Cabassud, B. Dahhou, and G. Casmatta, "Experimental application of the iterative learning control to the temperature control of batch reactor," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.

[270] M. Mezghani, G. Roux, M. Cabassud, B. Dahhou, M. V. Le Lann, and G. Casamatta, "Robust iterative learning control of an exothermic semibatch chemical reactor," *Math. Comput. Simul.*, vol. 57, no. 6, pp. 367–385, 2001.

[271] M. Mezghani, G. Roux, M. Cabassud, M. W. Le Lann, B. Dahhou, and G. Casamatta, "Application of iterative learning control to an exothermic semibatch chemical reactor," *IEEE Trans. Control Syst. Technol.*, vol. 10, no. 6, pp. 822–834, Nov. 2002.

[272] Y. Miyasato, "Iterative learning control of robotic manipulators by hybrid adaptation schemes," in *Proc. 42nd IEEE Conf. Decision Control*, Maui, HI, Dec. 2003, pp. 4428–4433.

[273] J. H. Moon, T. Y. Doh, and M. J. Chung, "A robust approach to iterative learning control design for uncertain systems," *Automatica*, vol. 34, no. 8, pp. 1001–1004, 1998.

[274] K. L. Moore, "Iterative learning control for deterministic systems," in *Advances Industrial Control*, New York: Springer-Verlag, 1993.

[275] K. L. Moore, "Iterative learning control—An expository overview," *Appl. Comput. Controls, Signal Process., Circuits*, vol. 1, no. 1, pp. 151–241, 1999.

[276] K. L Moore, "A matrix fraction approach to higher-order iterative learning control: 2-D dynamics through repetition-domain filtering," in *Proc. 2nd Int. Workshop Mutidimensional (nD) Syst.*, Czocha Castle, Lower Silesia, Poland, Jun. 2000, pp. 99–104.

[277] K. L. Moore, "On the relationhsip between iterative learning control and one-step ahead minimum prediction error control," in *Proc. Asian Control Conf.*, Shanghai, China, Jul. 2000, pp. 1861–1865.

[278] K. L. Moore, "An observation about monotonic convergence in discrete-time, P-type iterative learning control," in *Proc. 2001 IEEE Int. Symp. Intell. Control*, Mexico City, Mexico, Sep., pp. 45–49.

[279] K. L. Moore and V. Bahl, "Iterative learning control for multivariable systems with an application to mobile robot path tracking," in *Proc. Int. Conf. Autom., Robot., Control*, Singapore, Dec. 2000, pp. 396–401.

[280] K. L. Moore and Y. Q. Chen, "On monotonic convergence of high order iterative learning update laws," in *15th IFAC Congr. Invited Session High-order Iterative Learning Control*, Barcelona, Spain, Jul. 21–26, 2002, pp. 1–6.

[281] K. L. Moore and YangQuan Chen, "A separative high-order framework for monotonic convergent iterative learning controller design," in *Proc. 2003 Amer. Control Conf.*, Jun., pp. 3644–3649.

[282] K. L. Moore, M. Dahleh, and S. P. Bhattacharyya, "Iterative learning control: A survey and new results," *J. Robot. Syst.*, vol. 9, no. 5, pp. 563–594, 1992.

[283] K. L. Moore, "A non-standard iterative learning control approach to tracking periodic signals in discrete-time non-linear systems," *Int. J. Control*, vol. 73, no. 10, pp. 955–967, 2000.

[284] K. L. Moore, Y. Q. Chen, and V. Bahl, "Feedback controller design to ensure monotonic convergence in discrete-time, P-type iterative learning control," in *Proc. 2002 Asian Control Conf.*, Singapore, Sep., pp. 440–445.

[285] K. L. Moore and J.-X. Xu (Eds), "Special issue on iterative learning control," *Int. J. Control*, vol. 73, no. 10, pp. 819–999, 2000.

[286] K. L. Moore, "Multi-loop control approach to designing iterative learning controllers," in *Proc. 37th IEEE Conf. Decision Control*, Tampa, FL, Dec.1998, pp. 666–671.

[287] K. L. Moore, "An iterative learning control algorithm for systems with measurement noise," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec.1999, pp. 270–275.

[288] P. T. A. Nguyen and S. Arimoto, "Learning motion of dexterous Manipulation for a pair of multi-DOF fingers with soft-tips," *Asian J. Control*, vol. 4, no. 1, pp. 11–20, 2002.

[289] P. T. A. Nguyen, H.-Y. Han, S. Arimoto, and S. Kawamura, "Iterative learning of impedance control," in *Proc. 1999 IEEE/RSJ Int. Conf. Intell. Robots Syst.*, Kyongju, Korea, Oct.1999, pp. 653–658.

[290] G. Nijsse, M. Verhaegen, and N. J. Doelman, "A new subspace based approach to iterative learning control," presented at the 2001 Eur. Control Conf., Seminário de Vilar, Porto, Portugal, Sep.

[291] A. Nishiki, T. Sogo, and N. Adachi, "Tip position control of a one-link flexible arm by adjoint-type iterative learning control," in *Proc. 41st SICE Ann. Conf.*, Aug. 2002, pp. 1551–1555.

[292] J.-H. Noh, H.-S. Ahn, and D.-H. Kim, "Hybrid position/force control of a two-link SCARA robot using a fuzzy-tuning repetitive controller," presented at the 3rd Asian Control Conf., Shanghai, China, 2000.

[293] M. Norrlöf, "Comparative study on first and second order ILC-frequency domain analysis and experiments," in *Proc. 39th IEEE Conf. Decision Control*, Sydney, Australia, Dec. 2000, pp. 3415–3420.

[294] M. Norrlöf, "An adaptive approach to iterative learning control with experiments on an industrial robot," presented at the 2001 Eur. Control Conf., Seminário de Vilar, Porto, Portugal, Sep.

[295] M. Norrlöf, "An adaptive iterative learning control algorithm with experiments on an industrial robot," *IEEE Trans. Robot. Autom.*, vol. 18, no. 2, pp. 245–251, Apr. 2002.

[296] M. Norrlöf, "Iteration varying filters in iterative learning control," presented at the 3rd Asian Control Conf., Singapore, Sep. 2002.

[297] M. Norrlöf, "Disturbance rejection using an ILC algorithm with iteration varying filters," *Asian J. Control*, vol. 6, no. 3, pp. 432–438, 2004.

[298] M. Norrlöf and S. Gunnarsson, "A frequency domain analysis of a second order iterative learning control algorithm," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec.1999, pp. 1587–1592.

[299] M. Norrlöf and S. Gunnarsson, "Disturbance aspects of iterative learning control," *Eng. Appl. Artif. Intell.*, vol. 14, no. 1, pp. 87–94, 2001.

[300] M. Norrlöf and S. Gunnarsson, "Disturbance aspects of high order iterative learning control," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.
[301] M. Norrlöf and S. Gunnarsson, "Experimental comparison of some classical iterative learning control algorithms," *IEEE Trans. Robot. Autom.*, vol. 18, no. 4, pp. 636–641, Aug. 2002.
[302] M. Norrlöf and S. Gunnarsson, "Some new results on current iteration tracking error ILC," presented at the 3rd Asian Control Conf., Singapore, Sep. 2002.
[303] M. Norrlöf and S. Gunnarsson, "Time and frequency domain convergence properties in iterative learning control," *Int. J. Control*, vol. 75, no. 14, pp. 1114–1126, 2002.
[304] M. Norrlöf, "Iterative learning control: Analysis, design, and experiments" Ph.D. thesis, Linköping Studies in Science and Technology, Sweden, 2000.
[305] R. Ogoshi, T. Sogo, and N. Adachi, "Adjoint-type iterative learning control for nonlinear nonminimum phase system—Application to a planar model of a helicopter," in *Proc. 41st SICE Annu. Conf.*, Shanghai, China, Aug. 2002, pp. 1547–1550.
[306] S. J. Oh, "Synthesis and analysis of design methods for improved tracking performance in iterative learning and repetitive control," Ph.D. thesis, Columbia Univ., New York, 2004.
[307] M. Olivares, P. Albertos, and A. Sala, "Iterative learning controller design for multivariable systems," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.
[308] G. Oriolo, S. Panzieri, and G. Ulivi, "Learning optimal trajectories for non-holonomic systems," *Int. J. Control*, vol. 73, no. 10, pp. 980–991, 2000.
[309] D. H. Owens and K. Feng, "Parameter optimization in iterative learning control," *Int. J. Control*, vol. 76, no. 11, pp. 1059–1069, 2003.
[310] D. H. Owens and J. Hätönen, "Convex modifications to an iterative learning control law," presented at the 15th IFAC World Congr. Autom. Control, Barcelona, Spain, Jul. 2002.
[311] D. H. Owens and J. J. Hätönen, "A new optimality based adaptive ILC-algorithm," in *Proc. 7th Int. Conf. Control, Autom., Robot. Vision*, Singapore, Dec. 2002, pp. 1496–1501.
[312] D. H. Owens and G. Munde, "Error convergence in an adaptive iterative learning controller," *Int. J. Control*, vol. 73, no. 10, pp. 851–857, 2000.
[313] D. H. Owens and E. Rogers, "Iterative learning control-recent progress and open research problems," in *Learning Syst. Control, Inst. Elect. Eng. Seminar*, Birmingham, U.K., May 2000, pp. 7/1–7/3.
[314] D. H. Owens and E. Rogers, "Comments on 'On the equivalence of causal LTI iterative learning control and feedback control," by P. B. Goldsmith *Automatica*, vol. 40, no. 5, pp. 895–898, 2004.
[315] D. H. Owens, E Rogers, and K. L. Moore, "Analysis of linear iterative learning control schemes using repetitive process theory," *Asian J. Control*, vol. 4, no. 1, pp. 68–89, 2002.
[316] D. H. Owens, "The benefits of prediction in learning control algorithms," in *Inst. Elect. Eng. Two-Day Workshop Model Predictive Control: Technol. Appl.—Day 1*, London, U.K., Apr. 1999, pp. 3/1–3/3.
[317] D. H. Owens, N. A. Mann, E. Rogers, and M. French, "Analysis of linear iterative learning control schemes—A 2D systems/repetitive processes approach," *Multidimensional Syst. Signal Process.*, vol. 11, no. 1–2, pp. 125–177, 2000.
[318] D. H. Owens and G. S. Munde, "Universal adaptive iterative learning control," in *Proc. 37th IEEE Conf. Decision Control*, Tampa, FL, Dec. 1998, pp. 181–185.
[319] M. Pandit, S. Baque, and A. Spiess, "Performance of temperature measurement and control systems in industrial aluminium extruders," *Aluminium*, vol. 74, no. 1–2, pp. 54–57, 1998.
[320] M. Pandit and K. H. Buchheit, "Optimizing iterative learning control of cyclic production processes with application to extruders," *IEEE Trans. Control Syst. Technol.*, vol. 7, no. 3, pp. 382–390, May 1999.
[321] M. Pandit, W. Deis, H. Hengen, and V. Rothweiler, "The automation of aluminium extruders and its implementation with MoMAS—The mobile measurement and automation system for extruders," in *Aluminium Two Thousand: 5th World Congr. on Aluminium*, Rome, Italy, Mar. 2003.
[322] S. Pandit, M. Baque, W. Deis, and K. Muller, "Implementation of temperature measurement and control in aluminum extruders," presented at the 7th Int. Aluminum Extrusion Technol. Seminar, Chicago, IL, May 2000.
[323] K. H. Park and Z. Bien, "A generalized iterative learning controller against initial state error," *Int. J. Control*, vol. 73, no. 10, pp. 871–881, 2000.
[324] K. H. Park, Z. Bien, and D. H. Hwang, "Design of an iterative learning controller for a class of linear dynamic systems with time delay," *Proc. Inst. Elect. Eng., Control Theory Appl.*, vol. 145, no. 6, pp. 507–512, 1998.
[325] K. H. Park, Z. Bien, and D.H. Hwang, "A study on the robustness of a PID-type iterative learning controller against initial state error," *Int. J. Syst. Sci.*, vol. 30, no. 1, pp. 49–59, 1999.
[326] K.-H. Park and Z. Bien, "A generalized iterative learning controller against initial state error," *Int. J. Control*, vol. 73, no. 10, pp. 871–881, 2000.
[327] K.-H. Park and Z. Bien, "Intervalized iterative learning control for monotone convergence in the sense of sup-norm," in *Proc. 3rd Asian Control Conf.*, Shanghai, China, 2000, pp. 2899–2903.
[328] K.-H. Park and Z. Bien, "A study on iterative learning control with adjustment of learning interval for monotone convergence in the sense of sup-norm," *Asian J. Control*, vol. 4, no. 1, pp. 111–118, 2002.
[329] K.-H. Park and Z. Bien, "A study on robustness of iterative learning controller with input saturation against time-delay," presented at the 3rd Asian Control Conf., Singapore, Sep. 2002.
[330] W. Paszke, K. Galkowski, E. Rogers, and D. H. Owens, "H_∞ control of discrete linear repetitive processes," in *Proc. 42nd IEEE Conf. Decision Control*, Maui, HI, Dec. 2003, pp. 628–633.
[331] K. S. Peterson and A. G. Stefanopoulou, "Extremum seeking control for soft landing of an electromechanical valve actuator," *Automatica*, vol. 40, no. 6, pp. 1063–1069, 2004.
[332] M. Q. Phan, R. W. Longman, and K. L. Moore, "Unified formulation of linear iterative learning control," in *AAS/AIAA Space Flight Mech. Meet.*, Clearwater, FL., Jan. 2000, pp. AAA 00–106.
[333] M. Q. Phan and H. Rabitz, "A self-guided algorithm for learning control of quantum-mechanical systems," *J. Chemical Phys.*, vol. 110, no. 1, pp. 34–41, 1999.
[334] M. Q. Phan and R. W. Longman, "Higher-order iterative learning control by pole placement and noise filtering," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.
[335] M. Q. Phan and J. A. Frueh, "Model reference adaptive learning control with basis functions," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec. 1999, pp. 251–257.
[336] N. Phetkong, "Learning control and repetitive control of a high speed nonlinear cam follower system" Ph.D. thesis, Lehigh Univ., Bethehem, PA, 2002.
[337] D.-Y. Pi and K. Panaliappan, "Robustness of discrete nonlinear systems with open-closed-loop iterative learning control," in *Proc. 2002 Int. Conf. Mach. Learning Cybern.*, Nov. 2002, pp. 1263–1266.
[338] D. Pi, D. Seborg, J. Shou, Y. Sun, and Q. Lin, "Analysis of current cycle error assisted iterative learning control for discrete nonlinear time-varying systems," in *IEEE Int. Conf. Syst., Man, Cybern.*, Nashville, TN, Oct. 2000, pp. 3508–3513.
[339] R. W. Plotnik and A. M. and Longman, "Subtleties in the use of zero-phase low-pass filtering and cliff filtering in learning control," presented at the AAS/AIAA Astrodynamics Conf., Girdwood, AK, Aug. 2000.
[340] Y.-M. Pok, K.-H. Liew, and J.-X. Xu, "Fuzzy PD iterative learning control algorithm for improving tracking accuracy," in *1998 IEEE Int. Conf. Syst., Man, Cybern.*, San Diego, CA, Oct.1998, pp. 1603–1608.
[341] J. P. Predina and H. L. Broberg, "Tuned open-loop switched to closed-loop method for rapid point-to-point movement of a periodic motion control system," U.S. Patent 6,686,716, U.S. Pat. Office, Washington, DC, Feb. 2004.
[342] W. Z. Qian, S. K. Panda, and J. X. Xu, "Torque ripple minimization in PM synchronous motors using iterative learning control," *IEEE Trans. Power Electron.*, vol. 19, no. 2, pp. 272–279, Mar. 2004.
[343] W. Qian, S. K. Panda, and J. X. Xu, "Periodic speed ripples minimization in PM synchronous motors using repetitive learning variable structure control," presented at the 3rd Asian Control Conf., Singapore, 2002.
[344] W. Qian, S. K. Panda, and J. X. Xu, "Torque ripples reduction in PM synchronous motor using frequency-domain iterative learning control," in *Proc. 5th Int. Conf. Power Electron. Drive Syst.*, Nov. 2003, pp. 1636–1641.
[345] W. Qin and L. Cai, "A Fourier series based iterative learning control for nonlinear uncertain systems," in *Proc. 2001 IEEE/ASME Int. Conf. Adv. Intell. Mechatronics*, Jul. 2001, pp. 482–487.
[346] W. Qin and L. Cai, "A frequency domain iterative learning control for low bandwidth system," in *Proc. 2001 Amer. Control Conf.*, Arlington, VA, Jun. 2001, pp. 1262–1267.
[347] Z. Qu and J. Xu, "Learning unknown functions in cascaded nonlinear systems," in *Proc. 37th IEEE Conf. Decision Control*, Tampa, FL, Dec. 1998, pp. 165–169.

[348] Z. H. Qu, "An iterative learning algorithm for boundary control of a stretched moving string," *Automatica*, vol. 38, no. 5, pp. 821–827, 2002.

[349] Z. H. Qu and J. X. Xu, "Asymptotic learning control for a class of cascaded nonlinear uncertain systems," *IEEE Trans. Autom. Control*, vol. 47, no. 8, pp. 1369–1376, Aug. 2002.

[350] Z. Qu, "An iterative learning algorithm for boundary control of a stretched string on a moving transporter," presented at the 3rd Asian Control Conf., Shanghai, China, 2000.

[351] Z. Qu and J.-X. Xu, "Model-based learning controls and their comparisons using Lyapunov direct method," *Asian J. Control*, vol. 4, no. 1, pp. 99–110, 2002.

[352] J. D. Ratcliffe, T. J. Harte, J. J. Hätönen, P. L. Lewin, E. Rogers, and D. H. Owens, "Practical implementation of a model inverse optimal iterative learning controller on a gantry robot," in *Proc. IFAC Workshop Adaptive Learning Control Signal Process. IFAC Workshop Periodic Control Syst.*, Yokohama, Japan, 2004, pp. 687–692.

[353] A. Robertsson, D. Scalamogna, M. Grundelius, and R. Johansson, "Cascaded iterative learning control for improved task execution of optimal control," in *Proc. IEEE Int. Conf. Robot. Autom.*, Washington, DC, May 2002, pp. 1290–1295.

[354] E. Rogers, K. Galkowski, A. Gramacki, J. Gramacki, and D. H. Owens, "Stability and controllability of a class of 2-D linear systems with dynamic boundary conditions," *IEEE Trans. Circuits Syst. I, Fundamental Theory Appl.*, vol. 49, no. 2, pp. 181–195, 2002.

[355] E. Rogers, J. Lam, K. Galkowski, S. Xu, J. Wood, and D. H. Owens, "LMI based stability analysis and controller design for a class of 2D discrete linear systems," in *Proc. 40th IEEE Conf. Decision Control*, Orlando, FL, Dec. 2001, pp. 4457–4462.

[356] D. D. Roover and O. H. Bosgra, "Synthesis of robust multivariable iterative learning controllers with application to a wafer stage motion system," *Int. J. Control*, vol. 73, no. 10, pp. 968–979, 2000.

[357] D. D. Roover, O. H. Bosgra, and M. Steinbuch, "Internal-model-based design of repetitive and iterative learning controllers for linear multivariable systems," *Int. J. Control*, vol. 73, no. 10, pp. 914–929, 2000.

[358] I. Rotariu, R. Ellenbroek, and M. Steinbuch, "Time-frequency analysis of a motion system with learning control," in *Proc. 2003 Amer. Control Conf.*, Denver, CO, Jun. 2003, pp. 3650–3654.

[359] X.-E. Ruan, B.-W. Wan, and H.-X. Gao, "The iterative learning control for saturated nonlinear industrial control systems with dead zone," in *Proc. 3rd Asian Control Conf.*, Shanghai, China, 2000, pp. 1554–1557.

[360] M. Rzewuski, M. French, E. Rogers, and D. H. Owens, "Prediction in iterative learning control versus learning along the trials," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.

[361] M. Rzewuski, E. Rogers, and D. H. Owens, "A comparison of optimal iterative learning control schemes," in *Proc. IFAC Workshop Adaptation Learning Control Signal Process.*, 2001, pp. 77–82.

[362] S. S. Saab, "A discrete-time stochastic learning control algorithm," *IEEE Trans. Autom. Control*, vol. 46, no. 6, pp. 877–887, Jun. 2001.

[363] S. S. Saab, "On a discrete-time stochastic learning control algorithm," *IEEE Trans. Autom. Control*, vol. 46, no. 8, pp. 1333–1336, Aug. 2001.

[364] S. S. Saab, "A discrete-time stochastic iterative learning control algorithm for a class of nonlinear systems," in *Proc. 22nd IASTED Int. Conf. Modelling, Identification, Control*, Innsbruck, Austria, Feb. 2003, pp. 179–184.

[365] S. S. Saab, "Stochastic P-type/D-type iterative learning control algorithms," *Int. J. Control*, vol. 76, no. 2, pp. 139–148, 2003.

[366] S. S. Saab, "A stochastic iterative learning control algorithm with application to an induction motor," *Int. J. Control*, vol. 77, no. 2, pp. 144–163, 2004.

[367] N. C. Sahoo, J. X. Xu, and S. K. Panda, "Application of iterative learning for constant torque control of switched reluctance motors," in *Proc. 14th World Congr. IFAC*, Beijing, China, 1999, pp. 47–52.

[368] N. C. Sahoo, J. X. Xu, and S. K. Panda, "Low torque ripple control of switched reluctance motors using iterative learning," *IEEE Trans. Energy Convers.*, vol. 16, no. 4, pp. 318–326, Dec. 2001.

[369] S. K. Sahoo, S. K. Panda, and J. X. Xu, "Iterative learning based torque controller for switched reluctance motors," in *Proc. 29th Annu. Conf. IEEE Ind. Electron. Soc.*, Nov. 2003, pp. 2459–2464.

[370] S. K. Sahoo, S. K. Panda, and J. X. Xu, "Iterative learning-based high-performance current controller for switched reluctance motors," *IEEE Trans. Energy Convers.*, vol. 19, no. 3, pp. 491–498, Sep. 2004.

[371] S. K. Sahoo, S. K. Panda, and J. X. Xu, "Iterative learning control based direct instantaneous torque control of switched reluctance motors," in *Proc. IEEE 35th Annu. Power Electron. Spec. Conf., 2004*, Jun. 2004, pp. 4832–4837.

[372] N. Sakagami, M. Inoue, and S. Kawamura, "Theoretical and experimental studies on iterative learning control for underwater robots," presented at the 12th (2002) Int. Offshore Polar Eng. Conf., Kyushu, Japan, May 2002.

[373] N. Sakagami, M. Inoue, and S. Kawamura, "Theoretical and experimental studies on iterative learning control for underwater robots," *Int. J. Offshore Polar Eng.*, vol. 13, no. 2, pp. 120–127, 2003.

[374] N. Sakagami and S. Kawamura, "Time optimal control for underwater robot manipulators based on iterative learning control and time-scale transformation," in *Proc. OCEANS 2003*, Sep., pp. 1180–1186.

[375] E. Schamiloglu, G. T. Park, V. S. Soualian, C. T. Abdallah, and F. Hegeler, "Advances in the control of a smart tube high power backward wave oscillator," in *Proc. 12th IEEE Int. Pulsed Power Conf.*, Monterey, CA, Jun. 1999, pp. 852–855.

[376] W. G. Seo, B. H. Park, and J. S. Lee, "Adaptive fuzzy learning control for a class of nonlinear dynamic systems," *Int. J. Intell. Syst.*, vol. 15, no. 12, pp. 1157–1175, 2000.

[377] X. H. Shi, L. Shi, L. M. Wan, X. W. Yang, X. Xu, and Y. C. Liang, "A neural-network-based iterative controller of speed control for ultrasonic motors," in *Proc. 2003 Int. Conf. Mach. Learning Cybern.*, Nov. 2003, pp. 651–656.

[378] Z.-K. Shi, "Real-time learning control method and its application to AC-servomotor control," in *Proc. 2002 Int. Conf. Mach. Learning Cybern.*, Beijing, China, Nov. 2002, pp. 900–905.

[379] D. M. Shin, J. Y. Choi, and J. S. Lee, "A P-type iterative learning controller for uncertain robotic systems with exponentially decaying error bounds," *J. Robot. Syst.*, vol. 20, no. 2, pp. 79–91, 2003.

[380] J. Shou, D. Pi, and W. Wang, "Sufficient conditions for the convergence of open-closed-loop PID-type iterative learning control for nonlinear time-varying systems," in *Proc. IEEE Int. Conf. Syst., Man, Cybern., 2003*, Oct., pp. 2557–2562.

[381] J. Shou, Z. Zhang, and D. Pi, "On the convergence of open-closed-loop D-type iterative learning control for nonlinear systems," in *Proc. IEEE Int. Symp. Intell. Control*, Houston, TX, Oct. 2003, pp. 963–967.

[382] T. Sogo, "Stable inversion for nonminimum phase sampled-data systems and its relation with the continuous-time counterpart," in *Proc. 41st IEEE Conf. Decision Control*, Las Vegas, NV, Dec. 2002, pp. 3730–3735.

[383] T. Sogo, K. Kinoshita, and N. Adachi, "Iterative learning control using adjoint systems for nonlinear non-minimum phase systems," in *Proc. 39th IEEE Conf. Decision Control*, Sydney, Australia, Dec. 2000, pp. 3445–3446.

[384] R. W. Songchon and T. Longman, "Iterative learning control and the waterbed effect," presented at the AIAA/AAS Astrodynamics Specialist Conf., Denver, CO, Aug. 2000.

[385] T. Songchon, "The waterbed effect and stability in leraning/repetitive control" Ph.D. thesis, Columbia Univ., New York, 2001.

[386] T. Sugie, "On iterative learning control," in *Proc. Int. Conf. Inf. Res. Develop. Knowl. Soc. Infrastructure*, Mar. 2004, pp. 214–220.

[387] T. Sugie and K. Hamamoto, "Iterative learning control—An identification oriented approach," in *Proc. 41st SICE Annu. Conf.*, Aug. 2002, pp. 2563–2566.

[388] B. Sulikowski, K. Galkowski, E. Rogers, and D. H. Owens, "Output feedback control of discrete linear repetitive processes," *Automatica*, vol. 40, no. 12, pp. 2167–2173, 2004.

[389] D. Sun and J. K. Mills, "Performance improvement of industrial robot trajectory tracking using adaptive-learning scheme," *J. Dynamic Syst. Meas. Control—Trans. ASME*, vol. 121, no. 2, pp. 285–292, 1999.

[390] D. Sun and J. K. Mills, "Adaptive learning control of robotic systems with model uncertainties," in *Proc. IEEE Int. Conf. Robot. Autom.*, Leuven, May 1998, pp. 1847–1852.

[391] D. Sun and J. K. Mills, "High-accuracy trajectory tracking of industrial robot manipulator using adaptive-learning scheme," in *Proc. 1999 Amer. Control Conf.*, San Diego, CA, Jun., pp. 1935–1939.

[392] M. X. Sun and D. W. Wang, "Anticipatory iterative learning control for nonlinear systems with arbitrary relative degree," *IEEE Trans. Autom. Control*, vol. 46, no. 5, pp. 783–788, May 2001.

[393] M. X. Sun and D. W. Wang, "Initial condition issues on iterative learning control for non-linear systems with time delay," *Int. J. Syst. Sci.*, vol. 32, no. 11, pp. 1365–1375, 2001.

[394] M. X. Sun and D. W. Wang, "Iterative learning control design for uncertain dynamic systems with delayed states," *Dyn. Control*, vol. 10, no. 4, pp. 341–357, 2001.

[395] M. X. Sun and D. W. Wang, "Sampled-data iterative learning control for nonlinear systems with arbitrary relative degree," *Automatica*, vol. 37, no. 2, pp. 283–289, 2001.

[396] M. X. Sun and D. W. Wang, "Closed-loop iterative learning control for non-linear systems with initial shifts," *Int. J. Adaptive Control Signal Process.*, vol. 16, no. 7, pp. 515–538, 2002.

[397] M. X. Sun and D. W. Wang, "Iterative learning control with initial rectifying action," *Automatica*, vol. 38, no. 7, pp. 1177–1182, 2002.

[398] M. X. Sun and D. W. Wang, "Initial shift issues on discrete-time iterative learning control with system relative degree," *IEEE Trans. Autom. Control*, vol. 48, no. 1, pp. 144–148, Jan. 2003.

[399] M. X. Sun, D. W. Wang, and Y. Y. Wang, "Sampled-data iterative learning control with well-defined relative degree," *Int. J. Robust Nonlinear Control*, vol. 14, no. 8, pp. 719–739, 2004.

[400] M. Sun and D. Wang, "Sampled-data iterative learning control for a class of nonlinear systems," in *Proc. 1999 IEEE Int. Symp. Intell. Control/Intell. Syst. Semiotics*, Cambridge, MA, Sep., pp. 338–343.

[401] M. Sun and D. Wang, "Initial position shift problem and its ILC solution for nonlinear systems with a relative degree," in *Proc. 3rd Asian Control Conf.*, Shanghai, China, 2000, pp. 1900B1–1900B2.

[402] M. Sun and D. Wang, "Robust discrete-time iterative learning control: Initial shift problem," in *Proc. 40th IEEE Conf. Decision Control*, Orlando, FL, Dec. 2001, pp. 1211–1216.

[403] M. Sun and D. Wang, "Higher relative degree nonlinear systems with ILC using lower-order differentiations," *Asian J. Control*, vol. 4, no. 1, pp. 38–48, 2002.

[404] M. Sun and D. Wang, "Higher relative degree nonlinear systems with sampled-data ILC using lower-order differentiations," presented at the 3rd Asian Control Conf., Singapore, Sep. 2002.

[405] M. Sun, D. Wang, and G. Xu, "Initial shift problem and its ILC solution for nonlinear systems with higher relative degree," in *Proc. 2000 Amer. Control Conf.*, Chicago, IL, Jun., pp. 277–281.

[406] M. Sun, D. Wang, and G. Xu, "Sampled-data iterative learning control for SISO nonlinear systems with arbitrary relative degree," in *Proc. 2000 Amer. Control Conf.*, Chicago, IL, Jun., pp. 667–671.

[407] P. Sun, Z. Fang, and Z. Han, "Sampled-data iterative learning control for singular systems," in *Proc. 4th World Congr. Intell. Control Autom.*, Shanghai, China, Jun. 2002, pp. 555–559.

[408] K. K. Tan, H. F. Dou, Y. Q. Chen, and T. H. Lee, "High precision linear motor control via relay-tuning and iterative learning based on zero-phase filtering," *IEEE Trans. Control Syst. Technol.*, vol. 9, no. 2, pp. 244–253, Mar. 2001.

[409] K. K. Tan, S. N. Huang, and T. H. Lee, "Predictive iterative learning control," presented at the 3rd Asian Control Conf., Singapore, Sep. 2002.

[410] K. K. Tan, S. N. Huang, T. H. Lee, and S. Y. Lim, "A discrete-time iterative learning algorithm for linear time-varying systems," *Eng. Appl. Artif. Intell.*, vol. 16, no. 3, pp. 185–190, 2003.

[411] K. K. Tan, S. N. Huang, and S. Zhao, "A novel predictive and iterative learning control algorithm," *Control Intell. Syst.*, vol. 31, no. 1, pp. 1–9, 2003.

[412] K. K. Tan, S. Y. Lim, T. H. Lee, and H. F. Dou, "High-precision control of linear actuators incorporating acceleration sensing," *Robot. Comput.-Integr. Manuf.*, vol. 16, no. 5, pp. 295–305, 2000.

[413] K. K. Tan and J. C. Tang, "Learning-enhanced PI control of ram velocity in injection molding Machines," *Eng. Appl. Artif. Intell.*, vol. 15, no. 1, pp. 65–72, 2002.

[414] K. K. Tan and S. Zhao, "Iterative reference adjustment for high precision and repetitive motion control applications," in *Proc. 2002 IEEE Int. Symp. Intell. Control*, Vancouver, BC, Canada, Oct., pp. 131–136.

[415] Y. Tan, H. Sibarani, and Y. Samyudia, "Iterative learning strategy for a class of nonlinear controllers applied to constrained batch processes," presented at the 5th Asian Control Conf., Melbourne, Australia, Jul. 2004.

[416] X. Tang, L. Cai, and W. Huang, "A learning controller for robot manipulators using Fourier series," *IEEE Trans. Robot. Autom.*, vol. 16, no. 1, pp. 36–45, 2000.

[417] A. Tayebi, "Adaptive iterative learning control for robot manipulators," in *Proc. 2003 Amer. Control Conf.*, Denver, CO, Jun., pp. 4518–4523.

[418] A. Tayebi, "Adaptive iterative learning control for robot manipulators," *Automatica*, vol. 40, no. 7, pp. 1195–1203, 2004.

[419] A. Tayebi and J. X. Xu, "Observer-based iterative learning control for a class of time-varying nonlinear systems," *IEEE Trans. Circuits Syst. I—Fundam. Theory Appl.*, vol. 50, no. 3, pp. 452–455, 2003.

[420] A. Tayebi and M. B. Zaremba, "Iterative learning control for non-linear systems described by a blended multiple model representation," *Int. J. Control*, vol. 75, no. 16–17, pp. 1376–1384, 2002.

[421] A. Tayebi and M. B. Zaremba, "Robust ILC design is straightforward for uncertain LTI systems satisfying the robust performance condition," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.

[422] A. Tayebi and M. B. Zaremba, "Internal model-based robust iterative learning control for uncertain LTI systems," in *Proc. 39th IEEE Conf. Decision Control*, Sydney, Australia, Dec. 2000, pp. 3439–3444.

[423] M. B. Tayebi and A. Zaremba, "Exponential convergence of an iterative learning controller for time-varying nonlinear systems," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec.1999, pp. 1593–1598.

[424] S. P. Tian, S. L. Xie, and Y. L. Fu, "A nonlinear algorithm of iteration learning control based on analysis of vector charts," *Dyn. Continuous Discrete Impulsive Syst. B—Appl. Alg.*, pp. 154–161, 2003.

[425] Y.-P. Tian and X. Yu, "Robust learning control for a class of uncertain nonlinear systems," presented at the IFAC 15th World Congr., Barcelona, Spain, IFAC, Jul. 2002.

[426] R. Tousain, E. van der Meche, and O. Bosgra, "Design strategy for iterative learning control based on optimal control," in *Proc. 40th IEEE Conf. Decision Control*, Orlando, FL, Dec. 2001, pp. 4463–4468.

[427] T. Y. Townley and D. H. Owens, "Output steering using iterative learning control," presented at the 2001 Eur. Control Conf., Seminário de Vilar, Porto, Portugal, Sep.

[428] C. H. Tsai and C. J. Chen, "Application of iterative path revision technique for laser cutting with controlled fracture," *Opt. Laser Eng.*, vol. 41, no. 1, pp. 189–204, 2004.

[429] J. V. Amerongen, "Mechatronic design," presented at the 3rd Mechatronics Forum Int. Conf., Atlanta, GA, Sep. 2000.

[430] W. J. R. Velthuis, T. J. A. de Vries, P. Schaak, and E. W. Gaal, "Stability analysis of learning feed-forward control," *Automatica*, vol. 36, no. 12, pp. 1889–1895, 2000.

[431] M. H. A. Verwoerd, G. Meinsma, and T. J. A. de Vries, "On the use of noncausal LTI operators in iterative learning control," in *Proc. 41st IEEE Conf. Decision Control*, Las Vegas, NV, Dec. 2002, pp. 3362–3366.

[432] M. H. A. Verwoerd, G. Meinsma, and T. J. A. de Vries, "On equivalence classes in iterative learning control," in *Proc. 2003 Amer. Control Conf.*, Denver, CO, Jun., pp. 3632–3637.

[433] M. Verwoerd, "Iterative learning control: A critical review," Ph.D. thesis, Univ. Twente, Twente, Netherlands, 2004.

[434] V. Villagrán and D. Sbarbaro, "A new approach for tuning MIMO PID controllers using iterative learning," in *Proc. 14th World Congr. IFAC*, Beijing, China, 1999, pp. 247–252.

[435] V. J. Waissman, C. B. Youssef, and R. G. Vazquez, "Iterative learning control for a fedbatch lactic acid reactor," in *Proc. 2002 IEEE Int. Conf. Syst., Man Cybern.*, Oct.

[436] D. W. Wang and C. C. Cheah, "An iterative learning-control scheme for impedance control of robotic manipulators," *Int. J. Robot. Res.*, vol. 17, no. 10, pp. 1091–1104, 1998.

[437] D. Wang, "On anticipatory iterative learning control designs for continuous time nonlinear dynamic systems," in *Proc. 38th IEEE Conf. Decision Control*, Phoenix, AZ, Dec.1999, pp. 1605–1610.

[438] D. Wang, "On D-type and P-type ILC designs and anticipatory approach," *Int. J. Control*, vol. 73, no. 10, pp. 890–901, 2000.

[439] D. W. Wang, "Convergence and robustness of discrete time nonlinear systems with iterative learning control," *Automatica*, vol. 34, no. 11, pp. 1445–1448, 1998.

[440] M. Wang, B. Guo, Y. Guan, and H. Zhang, "Design of electric dynamic load simulator based on recurrent neural networks," in *Proc. IEEE Int. Electric Mach. Drives Conf.*, Jun. 2003, pp. 207–210.

[441] Q. Wang, Q.-R. Jiang, Y.-D. Han, J.-X. Xu, and X.-F. Bao, "Advanced modeling and control package for power system problems," in *Proc. IEEE 1999 Int. Conf. Power Electron. Drive Syst.*, Hong Kong, China, Jul., pp. 696–701.

[442] Y. C. Wang, C. J. Chien, and C. C. Teng, "Direct adaptive iterative learning control of nonlinear systems using an output-recurrent fuzzy neural network," *IEEE Trans. Syst. Man Cybern. B, Cybern.*, vol. 34, no. 3, pp. 1348–1359, Jun. 2004.

[443] Y.-C. Wang, C.-J. Chien, and C.-C. Teng, "A new recurrent fuzzy neural network based iterative learning control system," presented at the 3rd Asian Control Conf., Singapore, Sep. 2002.

[444] T. Watabe, M. Yamakita, T. Mita, and M. Ohta, "Output zeroing and iterative learning control for 3 link acrobat robot," in *Proc. 41st SICE Annu. Conf.*, 2002, pp. 2579–2584.

[445] H. P. Wen, M. Q. Phan, and R. W. Longman, "Bridging learning and repetitive control using basis functions," *Adv. Astronaut. Sci.*, vol. 99, Part 1, pp. 335–354, 1998.

[446] H.-P. Wen, "Design of adaptive and basis function based learning and repetitive control," Ph.D. dissertation, Columbia Univ., New York, 2001.

[447] S. L. Wirkander and R. W. Longman, "Limit cycles for improved performance in self-tuning learning control," in *Proc. AAS/AIAA Space Flight Mech. Meet.*, Breckenridge, CO, Feb. 1999, pp. 763–781.

[448] C. Wood, S. Rich, M. Frandsen, M. Davidson, R. maxfield, J. Keller, B. Day, M. Mecham, and K. Moore, "Mechatronic design and integration for a novel omni-directional robotic vehicle," presented at the 3rd Mechatronics Forum Int. Conf., Atlanta, GA, Sep. 2000.

[449] H. Wu, H. Kawabata, and K. Kawabata, "Decentralized iterative learning control schemes for large scale systems with unknown interconnections," in *Proc. 2003 IEEE Conf. Control Appl.*, Jun., pp. 1290–1295.

[450] H. Wu, Z. Zhou, S. Xiong, and W. Zhang, "Adaptive iteration learning control and its applications for FNS multi-joint motion," in *Proc. 17th IEEE Instrum. Meas. Technol. Conf.*, Baltimore, MD, May 2000, pp. 983–987.

[451] J. Xiao, Q. Song, and D. Wang, "A learning control scheme based on neural networks for repeatable robot trajectory tracking," in *Proc. 1999 IEEE Int. Symp. Intell. Control/Intell. Syst. Semiotics*, Cambridge, MA, Sep., pp. 102–107.

[452] Z. Xiong and J. Zhang, "Batch-to-batch optimal control of nonlinear batch processes based on incrementally updated models," *Proc. Inst. Elect. Eng. D—Control Theory Appl.*, vol. 151, no. 2, pp. 158–165, 2004.

[453] Z. H. Xiong and J. Zhang, "Product quality trajectory tracking in batch processes using iterative learning control based on time-varying perturbation models," *Ind. Eng. Chem. Res.*, vol. 42, no. 26, pp. 6802–6814, 2003.

[454] J.-X. Xu, "The frontiers of iterative learning control—part I," *J. Syst., Control, Inf.*, vol. 46, no. 2, pp. 63–73, 2002.

[455] J.-X. Xu, "The frontiers of iterative learning control—part II," *J. Syst., Control, Inf.*, vol. 46, no. 5, pp. 233–243, 2002.

[456] J. X. Xu, Y. Q. Chen, T. H. Lee, and S. Yamamoto, "Terminal iterative learning control with an application to RTPCVD thickness control," *Automatica*, vol. 35, no. 9, pp. 1535–1542, 1999.

[457] J. X. Xu, Q. P. Hu, T. H. Lee, and S. Yamamoto, "Iterative learning control with Smith time delay compensator for batch processes," *J. Process Control*, vol. 11, no. 3, pp. 321–328, 2001.

[458] J. X. Xu, T. H. Lee, and Y. Tan, "Enhancing trajectory tracking for a class of process control problems using iterative learning," *Eng. Appl. Artif. Intell.*, vol. 15, no. 1, pp. 53–64, 2002.

[459] J. X. Xu, T. H. Lee, and H. W. Zhang, "Analysis and comparison of iterative learning control schemes," *Eng. Appl. Artif. Intell.*, vol. 17, no. 6, pp. 675–686, 2004.

[460] J. X. Xu, S. K. Panda, Y. J. Pan, T. H. Lee, and B. H. Lam, "Improved PMSM pulsating torque minimization with iterative learning and sliding mode observer," in *Proc. 26th Annu. Conf. IEEE Ind. Electron. Soc.*, Nagoya, Japan, Oct. 2000, pp. 1931–1936.

[461] J. X. Xu, S. K. Panda, Y. J. Pan, T. H. Lee, and B. H. Lam, "A modular control scheme for PMSM speed control with pulsating torque minimization," *IEEE Trans. Ind. Electron.*, vol. 51, no. 3, pp. 526–536, Jun. 2004.

[462] J. X. Xu and Y. Tan, "A composite energy function-based learning control approach for nonlinear systems with time-varying parametric uncertainties," *IEEE Trans. Autom. Control*, vol. 47, no. 11, pp. 1940–1945, Nov. 2002.

[463] J. X. Xu and Y. Tan, "On the P-type and Newton-type ILC schemes for dynamic systems with non-affine-in-input factors," *Automatica*, vol. 38, no. 7, pp. 1237–1242, 2002.

[464] J. X. Xu and Y. Tan, "Robust optimal design and convergence properties analysis of iterative learning control approaches," *Automatica*, vol. 38, no. 11, pp. 1867–18, 2002.

[465] J. X. Xu and Y. Tan, "Analysis and robust optimal design of iteration learning control," in *Proc. 2003 Amer. Control Conf.*, Denver, CO, Jun., pp. 3038–3043.

[466] J. X. Xu, Y. Tan, and T. H. Lee, "Iterative learning control design based on composite energy function with input saturation," *Automatica*, vol. 40, no. 8, pp. 1371–1377, 2004.

[467] J. X. Xu and J. Xu, "On iterative learning from different tracking tasks in the presence of time-varying uncertainties," *IEEE Trans. Syst. Man Cybern. B, Cybern.*, vol. 34, no. 1, pp. 589–597, Feb. 2004.

[468] J. X. Xu and R. Yan, "Fixed point theorem-based iterative learning control for LTV systems with input singularity," *IEEE Trans. Autom. Control*, vol. 48, no. 3, pp. 487–492, 2003.

[469] J. X. Xu and R. Yan, "Iterative learning control design without a priori knowledge of the control direction," *Automatica*, vol. 40, no. 10, pp. 1803–1809, 2004.

[470] J.-X. Xu and W.-J. Cao, "Synthesized learning variable structure control approaches for repeatable tracking control tasks," in *Proc. 14th World Congr. IFAC*, Beijing, China, 1999.

[471] J.-X. Xu and Q. Ji, "New ILC algorithms with improved convergence for a class of non-affine functions," in *Proc. 37th IEEE Conf. Decision Control*, Tampa, FL, Dec.1998, pp. 660–665.

[472] J. X. Xu, T. H. Lee, and H. Tan, "Enhancing trajectory tracking for a class of process control problems using iterative learning," presented at the 3rd Asian Control Conf., Shanghai, China, 2000.

[473] J.-X. Xu, T. H. Lee, J. Xu, Q. Hu, and S. Yamamoto, "Iterative learning control with Smith time delay compensator for batch processes," in *Proc. 2001 Amer. Control Conf.*, Arlington, VA, Jun., pp. 1972–1977.

[474] J.-X. Xu, T. H. Lee, and H.-W. Zhang, "Comparative studies on repeatable runout compensation using iterative learning control," in *Proc. 2001 Amer. Control Conf.*, Arlington, VA, Jun., pp. 2834–2839.

[475] J.-X. Xu, T. H. Lee, and H.-W. Zhang, "On the ILC design and analysis for a HDD servo system," in *Proc. IFAC 15th World Congr.*, Barcelona, Spain, Jul. 2002.

[476] J.-X. Xu, K.-H. Liew, and C.-C. Hang, "Comparative studies of P and PI type iterative learning control algorithms for a class of process control," in *Proc. 14th World Congr. IFAC*, Beijing, China, 1999, pp. 165–170.

[477] J.-X. Xu and Y. Tan, "New iterative learning control approaches for nonlinear non-affine MIMO dynamic systems," in *Proc. 2001 Amer. Control Conf.*, Arlington, VA, Jun., pp. 896–901.

[478] J.-X. Xu and Y. Tan, "On the convergence speed of a class of higher-order ILC schemes," in *Proc. 40th IEEE Conf. Decision Control*, Orlando, FL, Dec. 2001, pp. 4932–4937.

[479] J.-X. Xu and Y. Tan, "On the robust optimal design and convergence speed analysis of iterative learning control approaches," presented at the IFAC 15th World Congr., Barcelona, Spain, Jul. 2002.

[480] J.-X. Xu and Y. Tan, *Linear and Nonlinear Iterative Learning Control*. Lecture Notes in Control and Informations Sciences. New York: Springer, 2003.

[481] J.-X. Xu, Y. Tan, and T.-H. Lee, "Iterative learning control design based on composite energy function with input saturation," in *Proc. 2003 Amer. Control Conf.*, Denver, CO, Jun., pp. 5129–5134.

[482] J.-X. Xu and B. Viswanathan, "On the integrated learning control method," in *Proc. 14th World Congress IFAC*, Beijing, China, 1999, pp. 495–500.

[483] J.-X. Xu and B. Viswanathan, "Recursive direct learning of control efforts for trajectories with different Magnitude scales," presented at the 3rd Asian Control Conf., Shanghai, China, 2000.

[484] J.-X. Xu, B. Viswanathan, and Z. Qu, "Robust learning control for robotic manipulators with an extension to a class of non-linear systems," *Int. J. Control*, vol. 73, no. 10, pp. 858–870, 2000.

[485] J.-X. Xu and W. Y. Wong, "Comparative studies on neuro-assisted iterative learning control schemes," in *Proc. 14th World Congr. IFAC*, Beijing, China, 1999, pp. 453–458.

[486] J.-X. Xu and J. Xu, "A new fuzzy logic learning control approach for repetitive trajectory tracking problems," in *Proc. 2001 Amer. Control Conf.*, Arlington, VA, Jun., pp. 3878–3883.

[487] J.-X. Xu and J. Xu, "Iterative learning control for non-uniform trajectory tracking problems," in *Proc. IFAC 15th World Congr.*, Barcelona, Spain, Jul. 2002.

[488] J.-X. Xu, J. Xu, and B. Viswanathan, "Recursive direct learning of control efforts for trajectories with different magnitude scales," *Asian J. Control*, vol. 4, no. 1, pp. 49–59, 2002.

[489] J.-X. Xu and R. Yan, "Fixed point theorem based iterative learning control for LTV systems with input singularity," in *Proc. 2003 Amer. Control Conf.*, Denver, CO, Jun., pp. 3655–3660.

[490] J.-X. Xu and R. Yan, "Iterative learning control design without a priori knowledge of control directions," in *Proc. 2003 Amer. Control Conf.*, Denver, CO, Jun., pp. 3661–3666.

[491] J. Xu and X. J. Xin, "Memory based nonlinear internal model: What can a control system learn," presented at the 3rd Asian Control Conf., Singapore, 2002.

[492] J. X. Xu and Z. H. Qu, "Robust iterative learning control for a class of nonlinear systems," *Automatica*, vol. 34, no. 8, pp. 983–988, 1998.

[493] J. X. Xu and B. Viswanathan, "Adaptive robust iterative learning control with dead zone scheme," *Automatica*, vol. 36, no. 1, pp. 91–99, 2000.

[494] M. Yamada, L. Xu, and O. Saito, "Iterative learning control of a robot manipulator using n-D practical tracking approach," in *Proc. 47th Midwest Symp. Circuits Syst.*, Jul. 2004, pp. II–565–II–568.

[495] M. Yamakita, M. Ueno, and T. Sadahiro, "Trajectory tracking control by an adaptive iterative learning control with artificial neural networks," in *Proc. 2001 Amer. Control Conf.*, Arlington, VA, Jun., pp. 1253–1255.

[496] M. Yamakita, T. Yonemura, Y. Michitsuji, and Z. Luo, "Stabilization of acrobat robot in upright position on a horizontal bar," in *Proc. IEEE Int. Conf. Robot. Autom.*, May 2002, pp. 3093–3098.

[497] X. G. Yan, I. M. Chen, and J. Lam, "D-type learning control for nonlinear time-varying systems with unknown initial states and inputs," *Trans. Inst. Meas. Control*, vol. 23, no. 2, pp. 69–82, 2001.

[498] D. R. Yang, K. S. Lee, H. J. Ahn, and J. H. Lee, "Experimental application of a quadratic optimal iterative learning control method for control of wafer temperature uniformity in rapid thermal processing," *IEEE Trans. Semicond. Manuf.*, vol. 16, no. 1, pp. 36–44, Feb. 2003.

[499] P.-H. Yang, "Control design for a class of unstable nonlinear systems with input constraint," Ph.D. dissertation, Univ. California, Berkeley, 1998.

[500] S. Y. Yang, X. P Fan, and A. Luo, "Experience based acquisition of the initial value for the iterative learning control inputs," *Control Decision*, vol. 19, no. 1, pp. 27–30, 2004.

[501] S. Yang, X. Fan, and A. Luo, "Adaptive robust iterative learning control for uncertain robotic systems," in *Proc. 4th World Congr. Intell. Control Autom.*, 2002, pp. 964–968.

[502] Y. Yang, "Injection molding control: From process to quality," Ph.D. dissertation, Hong Kong Univ. Sci. Tech., China, 2004.

[503] Z. Yao, H. Wang, and C. Yang, "A sort of iterative learning control algorithm for tracking of robot trajectory," *Acta Armamentarii*, vol. 25, no. 3, pp. 330–334, 2004.

[504] Y. Ye and D. Wang, "Multi-channel design for ILC with robot experiments," in *Proc. 7th Int. Conf. Control, Autom., Robot. Vision*, Dec. 2002, pp. 1066–1070.

[505] Y. Ye and D. Wang, "Better robot tracking accuracy with phase lead compensated ILC," in *Proc. IEEE Int. Conf. Robot. Autom.*, Taipei, Taiwan, Sep. 2003, pp. 4380–4385.

[506] C. B. Youssef, J. Waissman, and G. Vazquez, "An iterative learning control strategy for a fedbatch phenol degradation reactor," presented at the IASTED Int. Conf. Circuits, Signals, Syst., Cancun, Mexico, May 2003.

[507] H. Yu, M. Deng, T. C. Yang, and D. H. Owens, "Model reference parametric adaptive iterative learning control," presented at the IFAC 15th World Congr, Barcelona, Spain, Jul. 2002.

[508] S.-J. Yu, S.-L. Duan, and J.-H. Wu, "Study of fuzzy learning control for electro-hydraulic servo control systems," in *Proc. 2003 Int. Conf. Mach. Learning Cybern.*, Nov., pp. 591–595.

[509] S.-J. Yu, J.-H. Wu, and X.-W. Yan, "A PD-type open-closed-loop iterative learning control and its convergence for discrete systems," in *Proc. 2002 Int. Conf. Mach. Learning Cybern.*, Beijing, China, Nov., pp. 659–662.

[510] X. Zha and Y. Chen, "The iterative learning control strategy for hybrid active filter to dampen harmonic resonance in industrial power system," in *Proc. IEEE Int. Symp. Ind. Electron.*, Jun. 2003, pp. 848–853.

[511] X. Zha, J. Sun, and Y. Chen, "Application of iterative learning control to active power filter and its robustness design," in *Proc. IEEE 34th Annu. Conf. Power Electron. Spec.*, Jun. 2003, pp. 785–790.

[512] X. Zha, Q. Tao, J. Sun, and Y. Chen, "Development of iterative learning control strategy for active power filter," in *Proc. Can. Conf. Elect. Comput. Eng.*, May 2002, pp. 240–245.

[513] D. Zheng, "Iterative learning control of an electrohydraulic injection molding machine with smoothed fill-to-pack transition and adaptive filtering," Ph.D. dissertation, Univ. Illinois Urbana-Champaign, Urbana, 2002.

[514] C. Zhu, Y. Aiyama, and T. Arai, "Releasing Manipulation with learning control," in *Proc. 1999 IEEE Int. Conf. Robot. Autom.*, Detroit, MI, May, pp. 2793–2798.

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