Intelligent and Precision Control Laboratory

affiliated with

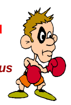
Ruth & Joel Spira Laboratories for Electro-Mechanical Systems
Ray W. Herrick Laboratories

NONLINEAR ADPTIVE ROBUST CONTROL (ARC) THEORY

Essence

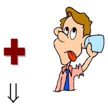
Good Body and Instinct

Fast Instantaneous Reaction !



Brain Power

Good Learning Ability !



Seamless integration of the fast reaction to immediate feedback information (e.g., nonlinear high-gain robust control) and the slow learning utilizing large amount of stored past feedback information that is available in the modern computer based control systems (e.g., adaptive control) to maximize the achievable control performance with built-in intelligences

Current Focus Areas

- **Control Performance Oriented Direct Adaptive Robust Control**
  - Learning law and control law are synthesized at the same time solely for reducing output tracking error, which leads to control systems having lower-orders
- **Estimation Based Indirect Adaptive Robust Control**
  - Decouple the constructions of control law and learning law so that better estimation model and on-line signal monitoring can be used to obtain accurate parameter and/or function estimates for secondary purposes such as prognostics
- **Integrated Direct/Indirect Adaptive Robust Control**
  - Intelligently integrating the fast dynamic compensation actions of direct ARC design with the good estimation process of indirect ARC design to synthesize controllers having both excellent control performance and parameter and function estimates
- **Nonlinear Adaptive Robust Observer Design for Virtual Sensing and Low Cost Implementation**
- **Neural Network Adaptive Robust Control for General Learning**
- **Repetitive Adaptive Robust Control for Repetitive Tasks**

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Visiting Scholars:

Prof. Hiroshi Fujimoto

Sponsors and Donors:

NSF, Maxtor Inc., Caterpillar Inc., Vickers Inc., Purdue Research Foundation, Purdue Electro-Hydraulic Research Center, …

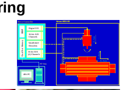
Research Focus:

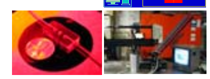
- **Developing a general framework for the design of intelligent and yet high precision/performance control algorithms**
- **Applications to the integrated design of intelligent and precision mechatronic systems**
- **Nonlinear observer design and neural network learning for virtual sensing, modeling, fault detection, diagnostics, and adaptive fault-tolerant control; Data fusion.**

MECHANICAL ENGINEERING
PURDUE UNIVERSITY

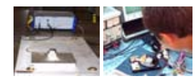
APPLICATIONS

- **Precision Control of Electro-Magnetic Motor Driven Mechanical Systems for Precision Manufacturing**
  - Machine Tools
  - High-Speed Linear Motors
  - Laser Micro-Machining Processes
  - Hard Disk Drives (HDD)
  - …

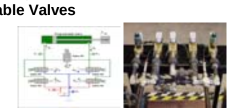




- **Ultra-Precision Control of Piezoelectrical Actuator Driven Mechanical Systems for Nanotechnology**
  - Control of Nano-positioning Stage
  - Dual Stage Ultra-High Density HDDs
  - …

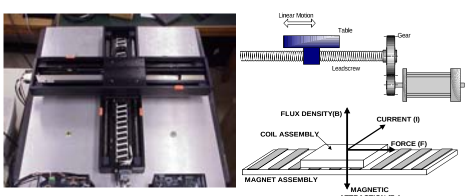


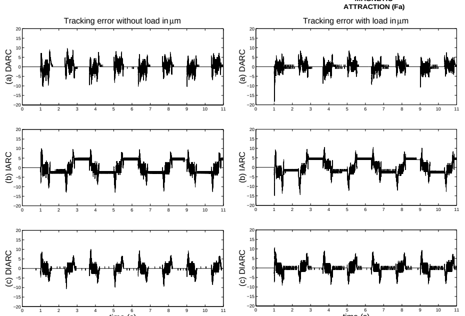
- **Energy Saving Control of Electro-Hydraulic Actuator Driven Systems with Novel Programmable Valves**
  - Hydraulic Servo-systems
  - Hydraulic Excavators
  - …



- **Coordinated Control of Multi-DOF Mechanical Systems and Multiple Robots for Factory Automation**
  - Trajectory Tracking Control of Robot Manipulators
  - Motion and Force Control of Robot Manipulators
    (a) in contact with a stiff surface with unknown stiffness
    (b) in contact with a rigid surface
  - Coordinated Control of Multiple Robot Manipulators

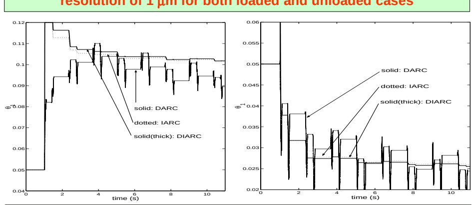
PRECISION MOTION CONTROL OF HIGH-SPEED LINEAR MOTOR DRIVE SYSTEMS





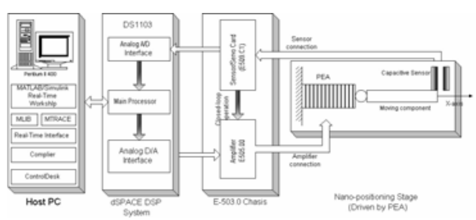
Tracking Errors for Point-to-Point Trajectory $(a_{max}=12m/sec^2, v_{max}=1m/sec)$

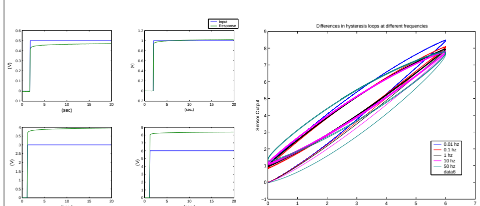
The above results demonstrate the excellent robust tracking performance of the proposed ARC algorithms – Tracking errors are mostly within 10 μm with final tracking error around the encoder resolution of 1 μm for both loaded and unloaded cases



The above plots show the accurate parameter estimation capability of the proposed DIARC and IARC – estimates of the inertia load converge to their actual values for both loaded and unloaded cases

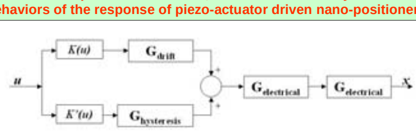
ULTRA-PRECISION MOTION CONTROL OF NANO-POSITIONERS



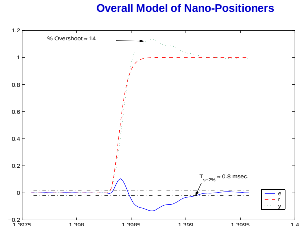


Step Responses to Different Input Magnitudes   Responses to Sinusoidal Inputs

The above plots show the drift, the non-linear and hysteresis behaviors of the response of piezo-actuator driven nano-positioners



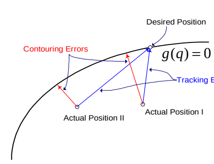
Overall Model of Nano-Positioners



Unit:
1 V = 1200 nm

Experimental Tracking Performance with an augmented pre-filter and lag compensator

COORDINATED CONTROL OF MULTI-DOF MECHANICAL SYSTEMS

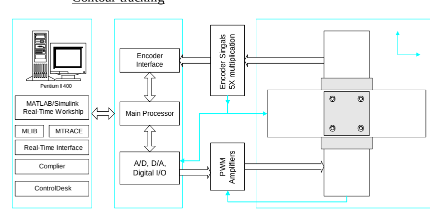


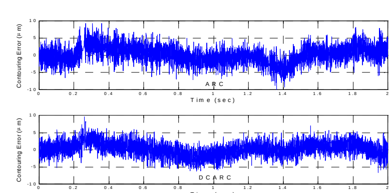
Contour tracking

Task Space

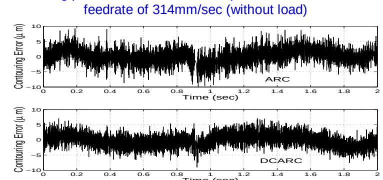
$$r=\begin{bmatrix} r_p \\ r_f \end{bmatrix},\quad \begin{matrix} r_p = f(q) \\ r_f = g(q) \end{matrix}$$

Transform the coordinated control problem to the control of MIMO nonlinear systems in task space





Contour tracking performance for a circular path with a radius of 0.1m and a feedrate of 314mm/sec (without load)



Contour tracking performance (with load)

The above results demonstrate the excellent robust contour tracking performance of the proposed ARC algorithms