MECHATRONICS LABORATORY
Florida International University

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Florida International University
Miami, FL
OUTLINE OF PRESENTATION

- Florida International University
- Mechatronics Laboratory
- Introduction
- Computational Tools
- Theoretical Background
- Applications
- Results
- Conclusion
FLORIDA INTERNATIONAL UNIVERSITY (FIU)

- Students: More than 35,000
- 52% Hispanic,
- 12% African-American,
- 5,000 are graduates
- 1,100 full-time faculty,
- Grants and awards: Over $75.5 million in fiscal year 2002-03
- Number one for Hispanics in the Bachelor and Masters Degree generation (The Hispanic Outlook in Higher Education)
- Number 42 for doctoral programs in 2004.
FLORIDA INTERNATIONAL UNIVERSITY (FIU)

COLLEGES AND SCHOOLS

School of Architecture
College of Arts and Sciences
School of Computer Science
School of Music
College of Business Administration
  Alvah H. Chapman, Jr. Graduate School of Business
School of Accounting
College of Continuing and Professional Studies
College of Education
College of Engineering
College of Health and Urban Affairs
  School of Health Sciences
  School of Nursing
  School of Social Work and Policy and Management
  Dr. Robert R. Stempel School of Public Health
School of Hospitality and Tourism Management
School of Journalism and Mass Communication
College of Law
FLORIDA INTERNATIONAL UNIVERSITY (FIU)
COLLEGE OF ENGINEERING

Located at the Engineering Center:
- 250,000-foot square building
- on 36 acres
- two miles from the University Park Campus
- includes: research centers, teaching laboratories, faculty offices, study areas, computing facilities, and research laboratories

Has the following departments:
- Biomedical Engineering
- Construction Management
- Civil and Environmental Engineering
- Electrical Engineering
- Industrial and Systems Engineering
- Mechanical and Materials Engineering
MECHATRONICS LABORATORY

- Located at the Engineering Center
- Established in 1990
- Research and teaching facility
  - Has excellent relationship with WPAFB for 14 years
  - Development of computational tools for
    - Automation of manufacturing operations
  - Nondestructive Testing (NDT)
- Teaching facility:
  - CAD, Mechatronics, Automatic Control, System Identification, Instrumentation
MANUFACTURING
Modeling milling operations, Tool breakage detection, Estimation of tool wear

SYSTEM IDENTIFICATION APPLICATIONS
Time Series, Neural Networks, Wavelet Transformation, Genetic Algorithm

HEALTH MONITORING
Detection of defects by using system identification techniques, software development

NDT
X-Ray image analysis

1990 1995 2000
INTRODUCTION

Needs:
- Manufacturing
  - Cost, quality,
  - Reliable operation
  - Quick maintenance

Solution:
Automated Manufacturing
On-line monitoring
Health monitoring

Main components of each solution:
Computational tools to interpret the sensory signals automatically
- Transformations
  - Wavelet transformation (WT)
  - S-transformation
- Mapping, classification
  - Neural networks (NN)
    - Trainable (Backpropagation)
    - Self-Learning (Adaptive Resonance Theory (ART2))
- Optimization - Diagnosis
  - Genetic algorithm (GA)
- Combination of above tools
  - WT + NN
  - NN + GA
- Interface with users – Graphic, database
THEORETICAL BACKGROUND

Transformations

Wavelet Transformation

\[ f(x) = \sum_{n=-\infty}^{\infty} c(n) \Phi_n(t) + \sum_{i=0}^{\infty} \sum_{j=-\infty}^{\infty} d(i, j) \Psi_{i,j}(t) \]

\[ c(n) = \int f(t) \Phi_n(t) \, dt \]

\[ d(i, j) = \int f(t) \Psi_{i,j}(t) \, dt \]

\[ \Phi(x) = \sum_n c(n) \Phi(2x - n) \]

\[ \Psi(x) = \sum_n (-1)^n c(n + 1) \Phi(2x - n) \]

S-Transformation

\[ S(\tau, f) = \int_{-\infty}^{\infty} h(t) \frac{|f|}{\sqrt{2\pi}} \exp \left[ -\frac{f^2(\tau-t)^2}{2} \right] \exp(-i2\pi ft) \, dt \]

\( \tau \) (time) determines the position of the translating window; F corresponds to the frequency.
THEORETICAL BACKGROUND
Mapping and Classification

SUPERVISED NEURAL NETWORKS

Backpropagation (BP)
Probabilistic Neural Networks (PNN)
Abductory Induction Mechanism (AIM)

UNSUPERVISED NEURAL NETWORKS

Probabilistic Neural Networks (PNN)
Abductory Induction Mechanism (AIM)
Adaptive Resonance Theory 2 (ART2)
• Genetic algorithm

Genetic Algorithm (Very flexible optimization tool)

1. Selection of the mating couples (parents)
2. Selection of the hereditary chromosome of the next generation
3. Gene crossover
4. Gene mutation
5. Creation of next generation (children)
6. Evolution
APPLICATIONS
Mapping – Modeling underground contamination, Metal cutting advisor
APPLICATIONS
Mapping – Estimation of thickness of overlapping materials from radiographic images

Simulation

X-Ray  Brass

Al

Direction of the radiation

TRAINING FILES

Irt-200-4-120.jpg  Irt-300-2-120.jpg

TEST FILES

Irt-200-4-120_x.jpg  Irt-300-2-120_x.jpg

THICKNESS ESTIMATION ACCURACY
(ALUMINUM)

THICKNESS ESTIMATION ACCURACY
(BRASS)

Experimental

Mapping – Estimation of thickness of overlapping materials from radiographic images

APPLICATIONS

Mapping – Estimation of thickness of overlapping materials from radiographic images

APPLICATIONS

Mapping – Estimation of thickness of overlapping materials from radiographic images

APPLICATIONS

Mapping – Estimation of thickness of overlapping materials from radiographic images

APPLICATIONS

Mapping – Estimation of thickness of overlapping materials from radiographic images
APPLICATIONS

WT + NN – Estimation of tool wear

Calculation of the approximation coefficients of the wavelet transformation and normalization of the data

NEURAL NETWORK

Wear (usage) estimation

Material:
POCOEDMC-3 machined, tested on Aluminum

ANALOG PNN (BASIC)

<table>
<thead>
<tr>
<th></th>
<th>TRAINING</th>
<th>TEST-ING</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANA LOG</td>
<td>PNN (BASIC)</td>
<td>ANALOG</td>
</tr>
<tr>
<td>TRAINING</td>
<td>AVERAGE</td>
<td>MAXIMUM</td>
</tr>
<tr>
<td></td>
<td>6.60</td>
<td>13.73</td>
</tr>
<tr>
<td></td>
<td>21.00</td>
<td>30.08</td>
</tr>
<tr>
<td></td>
<td>4.78</td>
<td>10.71</td>
</tr>
<tr>
<td></td>
<td>12.54</td>
<td>18.50</td>
</tr>
<tr>
<td></td>
<td>3.49</td>
<td>9.24</td>
</tr>
</tbody>
</table>

WT + Backpropagation type NN
APPLICATIONS

NN + GA – Composite Material Selection Advisor

CAD PACKAGE

STL FILE

PART DISPLAY

ORGANIZATION OF INPUTS TO THE NEURAL NETWORKS

TRAINED NEURAL NETWORK SYSTEM

BEST MATERIAL, PROCESS AND PARAMETERS

OPTIMIZATION RESULTS

DECISION SUPPORT SYSTEM

GENETIC ALGORITHM

Fiber volume

Volume

Complexity

Volume

Complexity

Volume

Complexity

Volume

Complexity

Fiber volume

Optimal output

Fiber volume

Optimal output

Fiber volume

Optimal output

Fittest Material

Fiber volume

Inter-face

APPLICATIONS

APPLICATIONS
Typical sinusoidal excitation signal:
\[ x(t) = a \sin(wt) \]

When the excitation hits different boundaries and echoes:
\[ \sum x_i(t) = \sum b_i a \sin(w(t + T_i)) \]

Same signal after a delay and attenuation:
\[ x(t) = b a \sin(w(t + T)) \]

**SIMULATION**

**EXPERIMENTAL**

- Perfect
- With a hole
- With a groove
S-Transformation

Genetic Algorithm

Computation of parameters with genetic algorithm

<table>
<thead>
<tr>
<th>Iterations</th>
<th>Time</th>
<th>Platform</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>2370</td>
<td>65S</td>
<td>Winxp</td>
<td>Visual basic</td>
</tr>
</tbody>
</table>

Estimation accuracy of the genetic algorithm

<table>
<thead>
<tr>
<th>l (waves)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_i$ (attenuation)</td>
<td>Theoretical</td>
<td>13</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Estimated</td>
<td>12.927104</td>
<td>15.140625</td>
<td>17.132813</td>
</tr>
<tr>
<td>$T_i$ (delay)</td>
<td>Theoretical</td>
<td>20</td>
<td>32</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>Estimated</td>
<td>20</td>
<td>32</td>
<td>150</td>
</tr>
</tbody>
</table>

Delay-Amplitude model represented the simulated signals accurately
**APPLICATIONS**

**Optimization – Diagnosis – Structural Health Monitoring**

**Genetic Algorithm**

Model wave and the signal (for A)

Model wave and the signal (for B)

Model wave and the signal (for C)

\[ \Sigma(\text{parameters of ref.} - \text{parameters of tested})^2 \]

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.73371E-09</td>
<td>1.14488E-08</td>
<td>6.86263E-08</td>
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</tbody>
</table>

Fitness (The parameters of the waves fixed)

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.000971</td>
<td>0.004199</td>
<td>0.007949</td>
</tr>
</tbody>
</table>

Fitness (The amplitude parameters optimized)

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.000697</td>
<td>0.003279</td>
<td>0.006574</td>
</tr>
</tbody>
</table>

Delay-Amplitude model represented the experimental signal and allowed detection of problems with a simple model.
**APPLICATIONS**

**Optimization – Diagnosis – Landing gear HM**

Simulated angular acceleration signal

The hydraulically retractable type landing gear of Lockheed F-16

Represented by the Slider-Crank inversion mechanism with \( r_3 \) as input variable

Position
\[
A = -2r_2r_3\cos(\theta_3); B = -2r_2r_3\sin(\theta_3); C = r_2^2 + r_1^2 - r_3^2
\]
\[
\theta_2 = 2\tan^{-1}\left[-\frac{B + \beta\sqrt{B^2 - C^2 + A^2}}{C - A}\right]; \beta = \pm 1
\]
\[
A = r_2\cos(\theta_2) - r_3\cos(\theta_3)
\]
\[
\theta_1 = 2\tan^{-1}\left[\frac{r_2 + \sigma\sqrt{r_2^2 - A^2 - r_1^2}}{A + r_1}\right]; \sigma = \pm 1; \theta_1 = \theta_3 - \frac{\pi}{2}
\]

Velocity
\[
\begin{bmatrix}
-r_3\sin(\theta_3) & r_3\sin(\theta_3) + r_1\sin(\theta_3) \\
r_2\cos(\theta_3) & -r_2\cos(\theta_3) - r_3\cos(\theta_3)
\end{bmatrix}
\begin{bmatrix}
\dot{\theta}_1 \\
\dot{\theta}_2
\end{bmatrix}
= \begin{bmatrix}
r_1\cos(\theta_3) \\
r_1\sin(\theta_3)
\end{bmatrix}
\]

Acceleration
\[
\begin{bmatrix}
r_3\sin(\theta_3) & r_3\sin(\theta_3) + r_1\sin(\theta_3) \\
r_2\cos(\theta_3) & -r_2\cos(\theta_3) - r_3\cos(\theta_3)
\end{bmatrix}
\begin{bmatrix}
\dot{\theta}_1 \\
\dot{\theta}_2
\end{bmatrix}
= \begin{bmatrix}
r_2\dot{\theta}_3\cos(\theta_3) - r_3\dot{\theta}_3\cos(\theta_3) + r_3\dot{\theta}_3\cos(\theta_3) - 2r_2\dot{\theta}_3\sin(\theta_3) + r_1\cos(\theta_3) - r_2\dot{\theta}_3\cos(\theta_3) + r_1\dot{\theta}_3\sin(\theta_3)
\end{bmatrix}
\]

**Sinusoidal oscillations**

+ **White noise**

1. Derek Morrison, Gregory Neff and Mohammad Zahraee, Aircraft Landing Gear Simulation and Analysis American Society for Engineering Education 1997 Annual Conference Session 1620
**APPLICATIONS**

**Optimization – Diagnosis – Landing gear HM**

Estimate:

\( a_1, a_2, t_1, t_2, t_3 \)

Position

\[
A = -2r_1r_2 \cos(\theta_1) \cos(\theta_2); B = -2r_1 \sin(\theta_1) \cos(\theta_2) \cos(\theta_2); C = r_1^2 + r_2^2 - r_1^2 - r_2^2
\]

\[
\theta_1 = 2 \tan \left( \frac{B + C \sqrt{B^2 - C^2 + A^2}}{C - A} \right), \quad \beta = \pm 1
\]

\[
A = r_1 \cos(\theta_1) - r_2 \cos(\theta_2)
\]

\[
\theta_1 = 2 \tan \left( \frac{r_1 r_2 A^2 - r_1^2 - r_2^2}{A + r_1} \right), \quad \sigma = \pm 1, \quad \theta_1 = \theta_1 - \frac{\pi}{2}
\]

Velocity

\[
\begin{bmatrix}
- r_1 \sin(\theta_1) & r_1 \sin(\theta_2) + r_2 \sin(\theta_1) & \theta_1
\end{bmatrix} - \begin{bmatrix}
\cos(\theta_1) & \cos(\theta_2) & \theta_2
\end{bmatrix}
\]

Acceleration

\[
\begin{bmatrix}
- r_2 \sin(\theta_1) & r_1 \sin(\theta_2) + r_2 \sin(\theta_1) & \theta_1
\end{bmatrix}
\]

\[
\begin{bmatrix}
- r_1 \cos(\theta_1) & - r_1 \cos(\theta_2) + r_2 \cos(\theta_1) & \theta_2
\end{bmatrix}
\]

\[
+ \begin{bmatrix} r_1 \theta_1^2 \cos(\theta_1) - r_1 \theta_1^2 \cos(\theta_2) - 2 r_1 \theta_1 \sin(\theta_1) + r_1 \theta_1 \cos(\theta_1) - r_2 \theta_1^2 \cos(\theta_2) \\
- r_1 \theta_2^2 \sin(\theta_1) + r_1 \theta_2^2 \sin(\theta_2) + 2 r_1 \theta_1 \cos(\theta_1) + r_1 \sin(\theta_1) - r_2 \theta_1^2 \sin(\theta_2) \end{bmatrix}
\]

Genetic algorithm

Linear acceleration at the hydraulic cylinder

\( a_1 \)

Angular acceleration at the pivot O

\( a_2 \)

\( t_1 \quad t_2 \quad t_3 \)

Velocity

Position

Optimization

Genetic algorithm

Multipurpose accelerometer
APPLICATIONS
Optimization – Diagnosis – Landing gear HM

GENETIC ALGORITHM

CASE I

a₁ = 0.0836
a₂ = -0.0836
₉₁ = 5
₉₂ = 10
₉₃ = 15

<table>
<thead>
<tr>
<th></th>
<th>a₁</th>
<th>a₂</th>
<th>t₁</th>
<th>t₂</th>
<th>t₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>THERETICAL</td>
<td>0.0863</td>
<td>-0.0836</td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>NO NOISE</td>
<td>0.08357</td>
<td>-0.08369</td>
<td>5.0098</td>
<td>10.0044</td>
<td>14.9561</td>
</tr>
<tr>
<td>+ SINE WAVE</td>
<td>0.08318</td>
<td>-0.08359</td>
<td>5.0513</td>
<td>10.0107</td>
<td>15.1087</td>
</tr>
<tr>
<td>+ SINE WAVE + WHITE NOISE</td>
<td>0.0822</td>
<td>-0.0850</td>
<td>5.005</td>
<td>10.065</td>
<td>15.43</td>
</tr>
</tbody>
</table>

CASE II

a₁ = 0.0803
a₂ = -0.0872
₉₁ = 5.205
₉₂ = 10.2057
₉₃ = 15

<table>
<thead>
<tr>
<th></th>
<th>a₁</th>
<th>a₂</th>
<th>t₁</th>
<th>t₂</th>
<th>t₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>THERETICAL</td>
<td>0.0803</td>
<td>-0.08072</td>
<td>5.025</td>
<td>10.2057</td>
<td>15</td>
</tr>
<tr>
<td>NO NOISE</td>
<td>0.0802</td>
<td>-0.0875</td>
<td>5.229</td>
<td>10.2318</td>
<td>14.9166</td>
</tr>
<tr>
<td>+ SINE WAVE</td>
<td>0.07969</td>
<td>-0.0863</td>
<td>5.2046</td>
<td>10.2100</td>
<td>15.7881</td>
</tr>
<tr>
<td>+ SINE WAVE + WHITE NOISE</td>
<td>0.07968</td>
<td>-0.0864</td>
<td>5.2000</td>
<td>10.2037</td>
<td>26.5214</td>
</tr>
</tbody>
</table>
APPLICATIONS

Interface - Visualization

FIU’s program

Paraform 3.0 Application

Point Cloud Mash Mode

Spring Mode

NURBS Surface Mode

Paraform 3.0 Application
APPLICATIONS

Interface - Database

• Preparation of a database

DATABASE INCLUDES:
12 fields - 246 article were put in,
211 only abstract, 23 linked to PDF, 12 article to be converted to PDF and linked
APPLICATIONS

Interface - Wireless application

1) Reporting SHM data to local station
2) Transmitting data to network
3) Storing the data
4) Processing data
5) Save results at the server
6) Operator gets the processed data from the network

S-transformation → PDA
X-ray analysis → PDA

Database → PDA
APPLICATIONS

Sensor Development

Terfenol-D

Coil

Magnetic head

Laser vibrometer

Magnetic alloy

Magnetic Response characteristics of the strip and small coil system depends on the strain
RESULTS

- TRANSFORMATION
  - To compress information: Wavelets
  - Time-Frequency analysis: S-Transformation

- MAPPING: Backpropagation type neural networks

- CLASSIFICATION
  - No model: Backpropagation, ART2
  - Raw data to estimation: WT + NN
  - Model is available: Genetic algorithm

- OPTIMIZATION
  - No model is available: NN +GA
CONCLUSION

Mechatronics Laboratory has made significant contribution in the following areas by using the computational tools:

- Nondestructive Testing
- Manufacturing
- Control
- Structural health monitoring and, diagnostic applications

The gained experience was used to improve the quality of the education.
Thank you very much for reviewing this presentation