Computational Intelligence for Industrial and Environmental Applications

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Summary

1. Introduction to industrial and environmental applications
2. Computational intelligence in industrial and environmental applications
3. Intelligent monitoring and control systems design methodology
   - Computational intelligence for sensors
   - Signal preprocessing
   - Feature extraction and selection
   - Computational intelligence for data fusion
   - Computational intelligence for classification and quality measurement
   - Computational intelligence for system optimization
4. Conclusions
Industrial Applications

Manufacturing Process

Quality Control
Environmental Applications

Monitoring Systems
Industrial and Environmental Analysis

- Boring, repetitive, exhausting and dangerous for human operators

- A computer does not get tired
Automatic Monitoring and Control Systems

- Accurate
- Often non invasive
- Standardized
Automatic Monitoring and Control Systems

Signal and image acquisition and preprocessing

Feature extraction and measurement

QUALITY MEASUREMENT

Analysis

Feature extraction and measurement

α
β
γ
...

d-dimensional vector
Technologies for Monitoring and Control Systems

- Sensors and measurement systems
- Signal processing
- Image processing
- Sensor data fusion
- Classification and clustering
Conventional Algorithmic Techniques

- Computational complexity
- Require a model
- Not able to learn from experience
Computational Intelligence in Monitoring and Control Systems

Fuzzy Systems

Intelligent

Adaptive

Neural Networks

Smarter

Evolvable

Evolutionary Computing
Composite Systems

TRADITIONAL PARADIGMS + COMPUTATIONAL INTELLIGENCE =

+ MORE DESIGN DEGREES OF FREEDOM
+ ACCURACY
+ PERFORMANCE
The Main Problem

Tackling *very* different aspects at the same time:

- instrumentation and measurement systems
- image and signal processing.
- feature extraction
- sensor fusion
- system modeling
- data analysis
- classification
How to Deal with Heterogeneous Aspects?

Nowadays:

- Separate issues
- Module-oriented solutions
- Ad-hoc solutions

- Limited optimization
- Limited reusability
- Limited integrability
A Comprehensive Design Approach

- Feature Extraction
- Sensor Fusion
- System Modeling
- Data Analysis
- Classification

Design methodology

Manufacturing Applications
Design Methodology for Intelligent Monitoring and Control Systems
A. Signal and image acquisition
B. Signal and image preprocessing
C. Feature extraction and selection
D. Data fusion
E. Classification and quality measurement
F. Control
G. System optimization
A. Signal and Image Acquisition

- **Conventional techniques:**
  - sensor enhancement
  - sensor linearization
  - sensor diagnosis
  - sensor calibration

- **Computational intelligence approaches**
  - self-calibration
  - non-linearities reduction
  - Error and faults detection
B. Signal Preprocessing

- **Signal preprocessing:**
  enhancing the signals and correcting the errors

- **Features processing:**
  extract from the input signals a set of features

Neural and fuzzy techniques for signal and feature processing:

- Adaptivity, intelligence, learning from examples, ...
C. Feature Extraction and Selection

- How many features?

<table>
<thead>
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<th></th>
<th>Complexity</th>
<th>Accuracy</th>
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<tbody>
<tr>
<td>Few features</td>
<td>↓</td>
<td>↓</td>
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<tr>
<td>Many features</td>
<td>↑</td>
<td>↑</td>
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?!?
Selection, Extraction, Selection and Extraction

Feature Selection

Feature 1
Feature 2
Feature 3
Feature 4
Feature 5
Feature 6

Feature Extraction

Feature 1
Feature 2
Feature 3
Feature 5

Feature Selection

Feature A
Feature B
Feature C
Feature D

Feature Extraction

Feature A
Feature B
Feature C
Feature D
Feature Extraction Algorithms

- Principal Component Analysis
- Linear Discriminant Analysis
- Independent Component Analysis
- Kernel PCA
- PCA network
- Nonlinear PCA
- Feed-Forward Neural Networks
- Nonlinear autoassociative network
- Multidimensional Scaling
- Self-Organizing Map (MAP)

Feature Selection Algorithms

- Exhaustive Search
- Branch and Bound
- Sequential Forward Selection
- Sequential Backward Selection
- Sequential Floating Search methods
D. Computational Intelligence for Data Fusion

- Fuse the available features/sensors signals to obtain more meaningful information

- **Sensor fusion**

- **Virtual sensors**
E. Computational Intelligence for Classification, Clustering and Pattern Recognition

Features

\[ \alpha \]
\[ \beta \]
\[ \gamma \]
\[ \ldots \]
\[ \text{d-dimensional vector} \]

Classifier

an integer: classification of the quality

\[ a \]

a floating point value: an index of quality
F. Control

- Neural-based control to capture the desired behavior through examples

- Fuzzy-based control to capture non-crisp definition of quantities
G. System Optimization

- System parameters difficult to fix
- Very often trial-and-error approaches
- Evolutionary computation techniques can solve this optimization task
Conclusions

- Monitoring and control are critical for advanced manufacturing processes and for maintaining an economical leading role.
- Monitoring is critical for advanced environmental applications and ensure a sustainable environment.
- A comprehensive design methodology should deal with all aspects in an integrated way.
- Computational intelligence offer additional opportunities for adaptable and evolvable systems.
Thanks!

Thanks!

Thanks!