AI Challenges in Cyber Manufacturing

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The smart factory represents a leap forward from self-contained automation to fully connected and intelligent manufacturing systems with learning capability over time.
Cyber Physical System

The smart factory represents a leap forward from self-contained automation to fully connected and intelligent manufacturing systems with learning capability over time.
**Smarting Factories**

1. Experience-based Smarting
2. Knowledge-based Smarting
Knowledge-Based Smarting

Benefit & Challenges

Knowledge-based Smarting

1. Dealing with Limited Data

2. Digital Twin Response Time
Combinatorial Optimization

\((2^N) \times N!\) Possibilities

Over 80 Bn choices

<table>
<thead>
<tr>
<th>N</th>
<th>((2^N) \times N!)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
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<tr>
<td>3</td>
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<tr>
<td>9</td>
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<td>10</td>
<td>3.72E+9</td>
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<tr>
<td>11</td>
<td>8.17E+10</td>
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</tbody>
</table>
Active Learning
• Optimal Exploration Design (Interactive & Iterative)

Quick Learning
• Faster, more observation of \((2^n)\times n!\) Possibilities
Responsive Cyber Twin

Sequence (?????????????)

Responsive Cyber Twin

Displacement
\[ X_1, X_2, X_3, \ldots, X_n \]
\[ Y_1, Y_2, Y_3, \ldots, Y_n \]
\[ Z_1, Z_2, Z_3, \ldots, Z_n \]

\[ 2^{11} \times 11! = 81,789,600 \] possible sequences
Responsive Cyber Twin

Sequence

Responsive Cyber Twin

Displacement

$X_1, X_2, X_3, \ldots X_n$

$Y_1, Y_2, Y_3, \ldots Y_n$

$Z_1, Z_2, Z_3, \ldots Z_n$

$2^{11} \times 11! = 81.7 \text{ Bn possible sequences}$
A set of sequence with high likelihood of resemblance (61 Scenarios)

- DHBaCkjiFEg
- BjkgHfcdEi
- JaIkFCdGhEB
- fJICGDEaBhk
- ejKaFBghDci
- AcgFDjEHlbK
- hFkIaGjDCBE
- KHCDAlEJfgb
- kFjiGEdacHb
- CEBkgJdaflh
- fhGEjIBdaKC
- HeKbIgadJfC

Each weld occurs at least once at every location

Each pair occurs at least once in the sequence

\[ 2^{11} \cdot 11! = 81.7 \text{ Bn possible sequences} \]
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Physics-Guided Mach. Lrn (PGML)

Welds Position
Welds Vicinity
Welds Orientation
Weld Resemblance

Sequence
(?????????????)

Responsive Cyber Twin

Displacement
$X_1, X_2, X_3, \ldots X_n$
$Y_1, Y_2, Y_3, \ldots Y_n$
$Z_1, Z_2, Z_3, \ldots Z_n$

$2^{11} \times 11! = 81.7 \text{ Bn possible sequences}$
Training set for machine learning (61 scenarios)

- DHBaCkjiFEg
- fJICGDEaBhk
- hFkIaGjDCBe
- CEbkgJdafIh
- fhGEjIBdaKC

- bjkagHfcdEi
- ejKaFBghDci
- AcgFDjEHlbK
- kFjiGEdacHb
- HeKbIgadJfC

Displacement

\[ X_1, X_2, X_3, \ldots, X_n \]
\[ Y_1, Y_2, Y_3, \ldots, Y_n \]
\[ Z_1, Z_2, Z_3, \ldots, Z_n \]

\[ 2^{11} \times 11! = 81.7 \text{Bn possible sequences} \]
Cyber Twin Validation

ML-Shadow  FEM

Training set for machine learning

DHBaCkjiFEg  bjkagHfcdEi  JaIkFCdGhEB
fJICGDEaBhk  ejKaFBghDci  AcgFDjEHbK
hFkIaGjDCBE  KHCDAlEjfgb  kFjiGEDacHb
CEbkgJdaflh  fhGEjIBdaKC  HeKbIgdJfC

fGHaJDcEKbi
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- DHBaCkjiFEg  bjkagHfcdEi  JaIkFCdGhEB
- fJICGDEaBhk  ejKaFBghDci  AcgFDjEHlbK
- hFkJaGjDCBE  KHCDAleJfgb  kFjiGEDacHb
- CEkkgJdaflh  fhGEjIBdaKC  HeKblIgadJfC

fGHaJDcEKbi
Training set for machine learning

DHBaCkjiFEg  bjkagHfcdeI  JaIkFCdGhEB  
fJICGDEaBhk  ejKaFBghDci  AcgFDjEHibK  
hFkIaGjDCBE  KHCDAlieJfgb  kFjiGEdacHb  
CEbkgJdafaIh  fhGEjIBdaKC  HeKblgdJfC  

fGHaJDcEKbi
Training set for machine learning

- DHBaCkjiFEg
- fJICGDEaBhk
- hFkIaGjDCBE
- CEbkgJd aflh

- bjkagHfcdei
- ejKaFBghDci
- KHCDAl ejfgb
- fhGEjIBdaKC

- JaIkFCdGhEB
- AcgFDjEHibK
- kFjiGEdachb
- HeKblgadJfc
Cyber Twin Validation

ML-Shadow | FEM
---|---
fGHaJ
fGHaJD
fGHaJDc
fGHaJDcE

ML-Shadow | FEM
---|---
fGHaJDcK
fGHaJDcKb
fGHaJDcKbi

Cool Down
Active Learning
• Optimal Exploration Design (Interactive & Iterative)

Quick Learning
• Faster, more observation of \((2^n)xn\) Possibilities
VAST DESIGN EXPLORATION

Sequence (????????????)

Responsive Cyber Twin

Displacement
$X_1, X_2, X_3, \ldots X_n$
$Y_1, Y_2, Y_3, \ldots Y_n$
$Z_1, Z_2, Z_3, \ldots Z_n$

$2^{111} 11! = 8.17 \times 10^{10}$ possible sequences
**Evolution of Smart Selection**

Training set for machine learning (61 scenarios)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Sequence</th>
<th>objective</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.999</td>
<td>0.597</td>
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<tr>
<td>2</td>
<td>jehbDGenlK</td>
<td>0.939</td>
<td>0.556</td>
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<tr>
<td>3</td>
<td>GbgejfeDhk</td>
<td>0.991</td>
<td>0.522</td>
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<tr>
<td>4</td>
<td>jehbDGlhSk</td>
<td>1.061</td>
<td>0.550</td>
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<td>5</td>
<td>LebeGfghlK</td>
<td>0.947</td>
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<tr>
<td>6</td>
<td>EbcgcDjGhK</td>
<td>1.118</td>
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<td>7</td>
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<td>sBsjjGcDlhlK</td>
<td>1.273</td>
<td>0.540</td>
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</table>

Displacement

- $X_1, X_2, X_3, \ldots, X_n$
- $Y_1, Y_2, Y_3, \ldots, Y_n$
- $Z_1, Z_2, Z_3, \ldots, Z_n$
Evolution of Smart Selection

Active Learning

Quick Learning

(G, e, b, j, c, l, f, a, D, h, k)

(i, d, e, f, J, H, g, a, b, c, K)
1. Click “Run” to weld the given sequence
   • A report is generated upon job completion;
Active Learning
to explore large design spaces with limited data (not typical big data mining)

Quick Learning
to enable interactive and iterative navigation and response time (not conventional FEA simulations)

Architecture of Smarting
Smart systems are not explicit programing, they are architectured to learn continually (autonomous vs. smart machine)
Active Learning
to explore large design spaces with limited data (not typical big data mining)

Quick Learning
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