AEC/APC SYMPOSIUM XII
Volume II
September 23-28, 2000
Caesars, Lake Tahoe, Nevada
Comparison of Run-to-Run Control Methods in Semiconductor Manufacturing Processes

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Introduction

- Run-to-Run (RtR) control methods are generalized.
- The set-valued RtR controllers with the ellipsoid approximation are compared with other RtR controllers by simulation according to the following principles:
  - A good RtR controller should be able to compensate for various disturbances, such as small drifts and large step disturbances.
  - It should be also able to deal with constraints, cost requirement, multiple targets, time delays, etc.
- Preliminary results show satisfactory performance of the set-valued RtR controller with ellipsoid approximation.
Generalization of RtR Control Methods

In the table, “Y” denotes “Applicable”; “N” denotes “Not applicable”, “L” means “Low”, “H” means “High”, and “M” means “Medium”.

<table>
<thead>
<tr>
<th>RtR control methods</th>
<th>Linear process</th>
<th>Light non-linear process</th>
<th>Severe non-linear process</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exponential Weight Moving Average (EWMA)</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>L</td>
</tr>
<tr>
<td>Machine learning</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>H</td>
</tr>
<tr>
<td>Least Square Recursive (LSR)</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>M</td>
</tr>
<tr>
<td>Probability</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>M</td>
</tr>
<tr>
<td>Artificial Neural Network (ANN)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>H</td>
</tr>
<tr>
<td>Set-valued</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
</tr>
</tbody>
</table>

The Set-valued RtR Controllers

- Two main ellipsoid algorithms available:
  - The Modified Optimal Volume Ellipsoid (MOVE) algorithm [3].
  - The Optimal Bounding Ellipsoid (OBE) algorithm. It was improved by Dasgupta and Huang, and is called Dasgupta Huang OBE (DHOB) algorithm [4].
- The corresponding controllers are called the SVR-MOVE controller and the SVR-DHOB controller respectively.
- Two schemes available for the SVR-DHOB controller:
  - The DHOB-MR controller uses the center of the ellipsoid as the estimate of the process model;
  - The DHOB-SV controller minimizes the worst-case cost.
Comparison of the SVR-MOVE Controller with the EWMA Controller

The simulation is based on the low pressure chemical vapor deposition (LPCVD) furnace process:

\[
R_1 = \exp(20.65 + 0.29 \ln P - 1.5189.21T^{-1} - 47.97Q^{-1})
\]

\[
R_2 = \frac{R_1(1 - 8838.93 \times 10^{-5} \times R_1 Q^{-1})}{1 + 8838.93 \times 10^{-5} \times R_1 Q^{-1}}
\]

- Inputs: T stands for the temperature, P the pressure, and Q the silane flow rate. They are constrained in certain scopes.
- Outputs: \( R_1 \) and \( R_2 \) are the deposition rates on the first and last wafer respectively.
- Noises: Drifts and white noises are added to the process.

When There Exists Drift Noise

- The EWMA controller is used to control only one process output \( R_1 \).
- The SVR-MOVE controller controls two processes \( R_1 \) and \( R_2 \).
- Both controllers perform well under the disturbance of drifts.

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When There Exists Shift Noise

- The EWMA controller is used to control only $R_1$.
- The EWMA controller needs one more step to return the process to target than the SVR-MOVE controller.
- The SVR-MOVE controller performs better than the EWMA controller under step disturbance.

Comparison of the SVR-MOVE Controller with the EWMA and the ANN EWMA Controllers

- The comparison is based on the second-order model in [1].
- Two cases are compared:
  - Small model error with a drift buried in white noise;
  - Large model error with a drift buried in white noise.
- The process controlled by the EWMA controller is often unstable in both cases for even conservative weights;
- The process controlled by the ANN-EWMA controller is unstable in the large model error case.
- The processes controlled by the SVR-MOVE controller are stable with proper selection of parameters.
Process Controlled by the SVR-MOVE Controller

There is a small model error

![Graph showing small model error comparison]

There is a large model error

![Graph showing large model error comparison]

Comparison of the SVR-DHOBE Algorithm with the OAQC Algorithm

- The process models and environment noises are exactly the same as those in [2].
- Partial simulation result is shown in the following table:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
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<th>1</th>
<th>2</th>
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<tbody>
<tr>
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<td>OAQC</td>
<td>DHOBE-MR</td>
<td>DHOBE-SV</td>
<td>OAQC</td>
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<tr>
<td>Y1</td>
<td>1719.7</td>
<td>1754.7</td>
<td>1787.7</td>
<td>1718.2</td>
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<td>Y2</td>
<td>168.4</td>
<td>157.3</td>
<td>168.1</td>
<td>165.7</td>
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<tr>
<td>MSE1</td>
<td>288.9</td>
<td>259.7</td>
<td>228.2</td>
<td>291.0</td>
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<tr>
<td>MSE2</td>
<td>79.2</td>
<td>67.5</td>
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<table>
<thead>
<tr>
<th>Scenario</th>
<th>2</th>
<th>2</th>
<th>3</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OAQC</td>
<td>DHOBE-MR</td>
<td>DHOBE-SV</td>
<td>OAQC</td>
</tr>
<tr>
<td>Y1</td>
<td>1781.9</td>
<td>1807.4</td>
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<tr>
<td>Y2</td>
<td>165.0</td>
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<td>189.1</td>
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<tr>
<td>MSE1</td>
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<td>211.9</td>
<td>350.2</td>
<td>280.8</td>
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<tr>
<td>MSE2</td>
<td>74.8</td>
<td>86.1</td>
<td>99.2</td>
<td>96.0</td>
</tr>
</tbody>
</table>

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Comparison of the SVR-DHOBE Algorithm with the OAO Algorithm (Cont’d)

• For detailed simulation processes and comparison figures, please refer to [4].
• The performance of the two SVR-DHOBE controllers is comparable to the OAO controller.
• There is no big difference in the performance of the two SVR-DHOBE controllers.
• This comparison also shows that it is insufficient to use linear models to approximate severe nonlinear processes.

Comparison of the SVR-MOVE Controller with the SVR-DHOBE Controller

• Difference between the two ellipsoid algorithms:
  – The derivation of the MOVE algorithm is based on a geometrical point of view.
  – The DHOBE algorithm uses a Recursive Least Square (RLS) scheme to update the ellipsoid.
• The comparison is conducted on:
  – an almost linear photoresist process I (Figure a: SVR-MOVE; Figure b: SVR-DHOBE);
  – photoresist process I when white noises in the process are removed and only the drifts exist (Figure c: SVR-MOVE; Figure d: SVR-DHOBE);
  – a full second-order nonlinear photoresist process II (Figure e: SVR-MOVE; Figure f: SVR-DHOBE).
Photoresist Process I Controlled by Two Set-valued RrR Controllers

Figure a

Figure b

Figure c

Figure d

Photoresist Process II Controlled by Two Set-valued RrR Controllers

Figure e

Figure f

- Simulations show that both controllers perform well.
- However the DHOBE algorithm has small overshoots, which affects the control quality slightly.
Summary

- Several important RtR control methods are compared in this paper.
- Preliminary simulations show that the set-valued RtR controller with ellipsoid approximation has better or comparable performance over some other RtR controllers.
- In some cases, the SVR-MOVE controller performs better than the SVR-DHOBE controller.
- It also shows that it is insufficient to use linear models to approximate severe nonlinear processes.
- More simulations will be conducted in the near future.

References


