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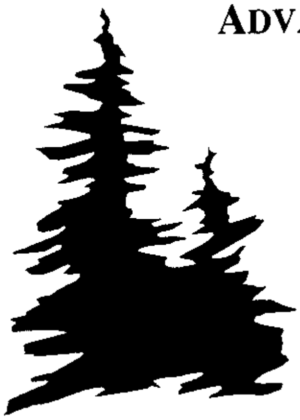
PROCEEDINGS VOLUME II



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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".

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

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 (DHOBE) algorithm [4].
- The corresponding controllers are called the SVR-MOVE controller and the SVR-DHOBE controller respectively.
- Two schemes available for the SVR-DHOBE controller:
  - The DHOBE-MR controller uses the center of the ellipsoid as the estimate of the process model;
  - The DHOBE-SV controller minimizes the worst-case cost.

Comparison of the SVR-MOVE Controller with the EWMA Controller

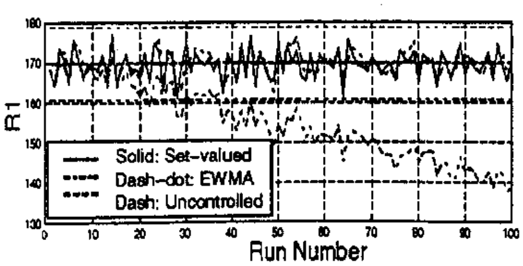
The simulation is based on the low pressure chemical vapor deposition (LPCVD) furnace process:

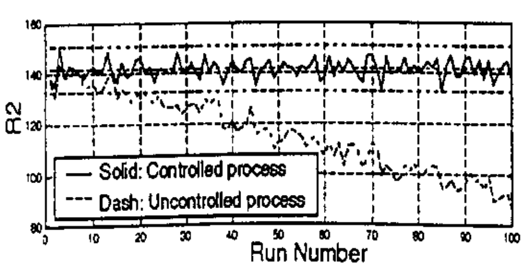
$$R_1 = \exp(20.65 + 0.29 \ln P - 15189.21 T^{-1} - 47.97 Q^{-1})$$

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

- 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.

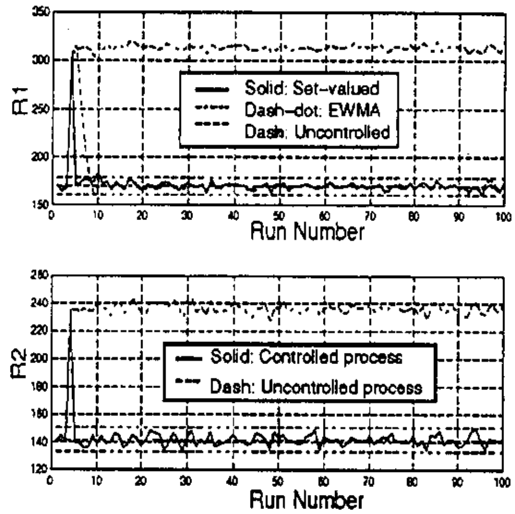
When There Exists Drift Noise





- 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.

When There Exists Shift Noise



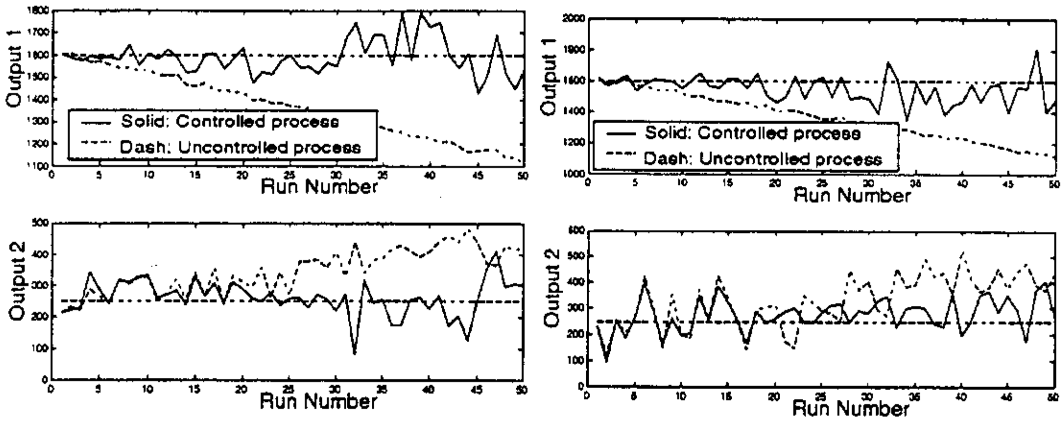
- The EWMA controller is used to control only R_1.
- The EWMA controller needs one more step to return the process to target than the SVR-MOVE controller.
- The SVR-MOVE controller performs better than the EWMA controller under step disturbance.

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　　　There is a large model error



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:

Scenario	1	1	1	2
Method	OAQC	DHOBE-MR	DHOBE-SV	OAQC
Y1	1719.7	1754.7	1787.7	1718.2
Y2	168.4	157.3	168.1	165.7
MSE1	288.9	259.7	228.2	291.0
MSE2	79.2	67.5	76.9	78.2

Scenario	2	2	3	3	3
Method	DHOBE-MR	DHOBE-SV	OAQC	DHOBE-MR	DHOBE-SV
Y1	1781.9	1807.4	1661.2	1741.4	1747.0
Y2	165.0	177.5	189.2	189.1	190.8
MSE1	234.2	211.9	350.2	280.8	275.9
MSE2	74.8	86.1	99.2	96.0	98.3

Comparison of the SVR-DHOBE Algorithm with the OAQC 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 OAQC 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 RtR Controllers

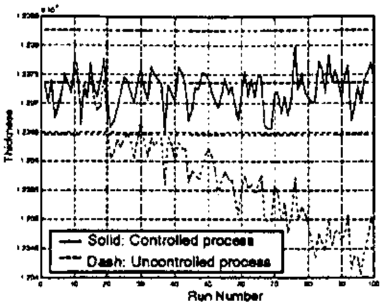


Figure a

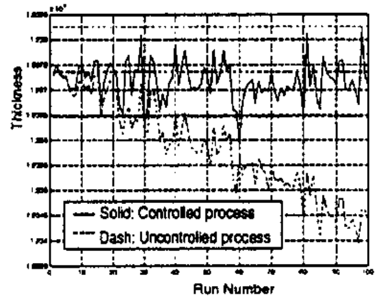


Figure b

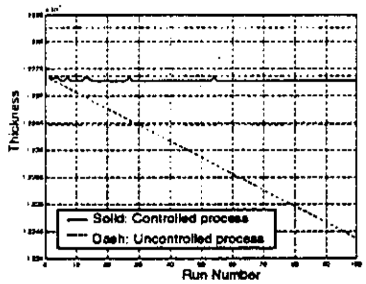


Figure c

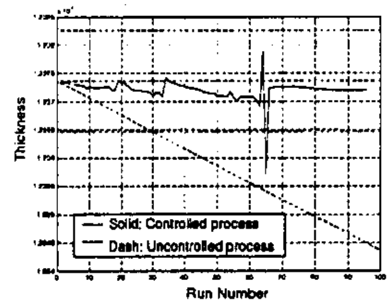


Figure d

Photoresist Process II Controlled by Two Set-valued RtR Controllers

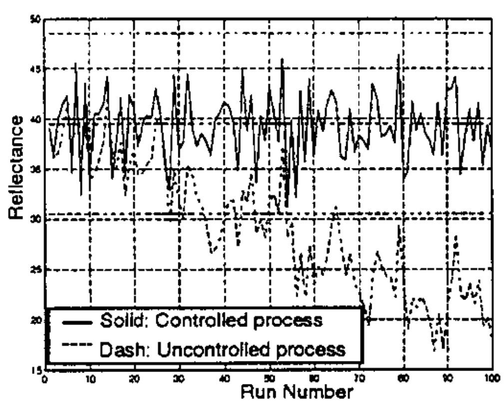


Figure e

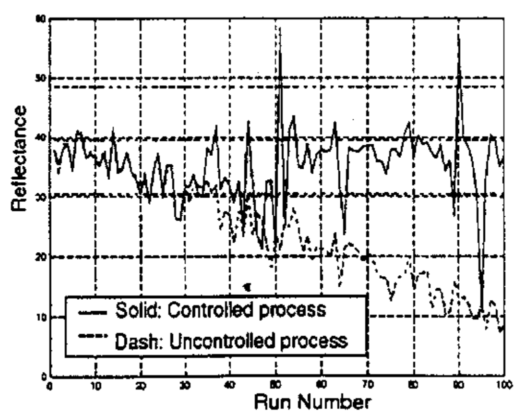


Figure f

- 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.

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