A Statistical Approach for Maintenance Management in Semiconductor Manufacturing Processes

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Mainteance Management Policies

1) Run-to-Failure Maintenance
When repairs or restore actions are performed only after the occurrence of a failure.

"If it’s not broken don’t fix it”

2) Preventive Maintenance
When repairs or restore actions are performed before the occurrence of a failure.

The main approaches to Maintenance Management.

Data Description

- **Equipment** - The EPI tool is composed of three independent chambers that can be considered as different machines. Each chamber of the EPI tool is equipped by four heating lamps that are in charge of warming up the wafer to the suitable temperature and two pyrometers that register the wafer temperatures on the two sides.

Kalman Predictor

The PdM system proposed is based on two assumptions.

**Assumption 1**
The evolution of \( x \) is event driven (i.e. it is determined by the equipment usage and it does not depend on the continuous time variable).

**Under Assump. 1** it is possible to consider the evolution of \( x \) as a discrete system \( x_k \), with \( k = 0, 1, \ldots, K \).

**Assumption 2**
The evolution of \( x \) can be approximated by

\[
x(k+1) = x_k + \Delta x_k + w_k,
\]

where \( \Delta x \) indicates the derivative of \( x \), \( v(k) \sim f(x) \) a generic density distribution, while the observed temperature difference \( y(k) \) can be defined by

\[
y(k) = x_k + w(k),
\]

where \( w(k) \sim N(0, H) \).

Assumption 2 is derived from observations of the process and describe the usual behavior of \( x \) to keep drifting towards a taken direction.

Particle Filter

If assumption \( v(k) \sim N(0, Q) \) does not hold true than the a posteriori estimation of \( \hat{x}_k \), given the measurements \( y_k \), can be obtained by using Sequential Monte Carlo Methods (SMCM), or Particle Filters.

Such methods provide suboptimal filtering algorithms that can be exploited when the noise distributions are not Gaussian.

In the SMCM approach, the a posteriori density function is represented by using a set of \( N_p \) random samples (particles) with associated weights.

The estimates are then computed based on such particles and weights by averaging.

Let \( (x_1^i, \ldots, x_k^i) \) for \( i = 0, \ldots, N_p \) be the set of particles and \( (w_1^i, \ldots, w_k^i) \) the associated weights such that \( \sum_{i=1}^{N_p} w_k^i = 1 \) for every \( i = 0, \ldots, k \).

The a posteriori distribution can be approximated as

\[
p_{\text{post}}(x_k | y_1, \ldots, y_k) \approx \sum_{i=1}^{N_p} w_k^i \delta(x_k - x_k^i),
\]

where \( \delta \) is the Dirac function, and the update equation for the weights is given by

\[
w_k^i = w_k^i \frac{p(y_k | x_k^i)}{p(y_k | x_k^i)} \frac{1}{f(x_k | \hat{x}_{k-1}^i, y_k)},
\]

where \( f(\cdot) \) is a proposal distribution called importance density.

A simple choice for \( f(x_k | \hat{x}_{k-1}^i, y_k) \) is the a priori distribution of the state \( p(x_k | \hat{x}_{k-1}) \).

According to such choice the previous becomes

\[
w_k^i = w_k^i \cdot p(y_k | x_k^i)
\]

As the number \( N_p \) increases, the estimates converge to the real state.

The main drawback of such approach is its high computational complexity.

Experimental

The two algorithms provide, thanks to the probabilistic framework, a distribution of the estimation error: the most important outcome of the PdM module is actually a confidence level, a probability of control action need at next step.

The performances of the two filters have been tested on real Fab data: in the Figure below it can be seen how the two approaches have similar performances.

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