PROCESS MONITORING OF THREE TANK SYSTEM

Outline

- Introduction
- Automation system
- PCA method
- Process monitoring with T^2 and Q statistics
- Conclusions

Introduction

- Monitoring system for the level and temperature of a mixing tank system in closed loop
- Operated with the DeltaV automation system
- Principal component analysis (PCA) method
- Monitoring the time series of Q and T^2 statistics

The three tank system

Automation system

- DeltaV automation system (v 11.3)
- Hardware: a professionalPLUS work station, a control unit, I/O units, a power supply and Foundation fieldbus communication system
- Software: DeltaV Explorer, Control Studio, and DeltaV Operate Configure, Process History View and DeltaV Insight
- Data can be collected from the historian database by MS Excel Program

PCA method 1/2

- Basic idea of PCA is to reduce the dimensionality of a set considering a large number of interrelated variables, while retaining as much as possible of a variation present in a data set
- **Target:** transforming the measured data to a new set of variables, the principal components, which are uncorrelated
- These principal components are ordered so that the first few retain most of the variation present in all of the original data
- In this work I have collect data matrix **X** with two input and two output, and columns of **X** are autoscaled
- Next step to calculate PCA is to construct the covariance matrix

$$\mathrm{cov}(\mathbf{X})=\mathbf{X}^{\mathrm{T}}\mathbf{X}/(m-1)$$

PCA method 2/2

- Next step to calculate PCA is to construct the eigenvalues λ_i associated with the eigenvectors p_i as

$$\mathrm{cov}(\mathbf{X})p_i = \lambda_i p_i$$

- Usually less than the entire principal components are used. It can calculate by cumulative sum of variances and select the principal component as over 72 percent of the total variance

- PCA model can be used in monitoring by plotting of Q and T^2 statistics
- Q statistic indicates how well each sample conforms to the PCA model, and it can be calculate as

$$Q = e_i e_i^T = x_i(\mathbf{I}-\mathbf{P}_k\mathbf{P}_k^T)x_i^T$$

- T^2 statistic measures the variation in each sample within the PCA model, and it can be calculate as

$$T^2 = t_i\lambda^{-1}t_i^T = x_i\mathbf{P}\lambda^{-1}\mathbf{P}^Tx_i^T$$

Upper confidence limits for statistics Q and T^2

- The upper limit for statistic Q_α can be calculated as

$$Q_\alpha = \theta_1[(h_0 c_\alpha \sqrt{2\theta_2})/\theta_1 + 1 + (\theta_2 h_0(h_0-1))/\theta_1^2]^{1/h_0}$$

with

$$\theta_i = \sum_{j=k+1}^{n} \lambda_j^i \quad \text{and} \quad h_0 = 1-(2\theta_1\theta_2)/2\theta_3^2$$

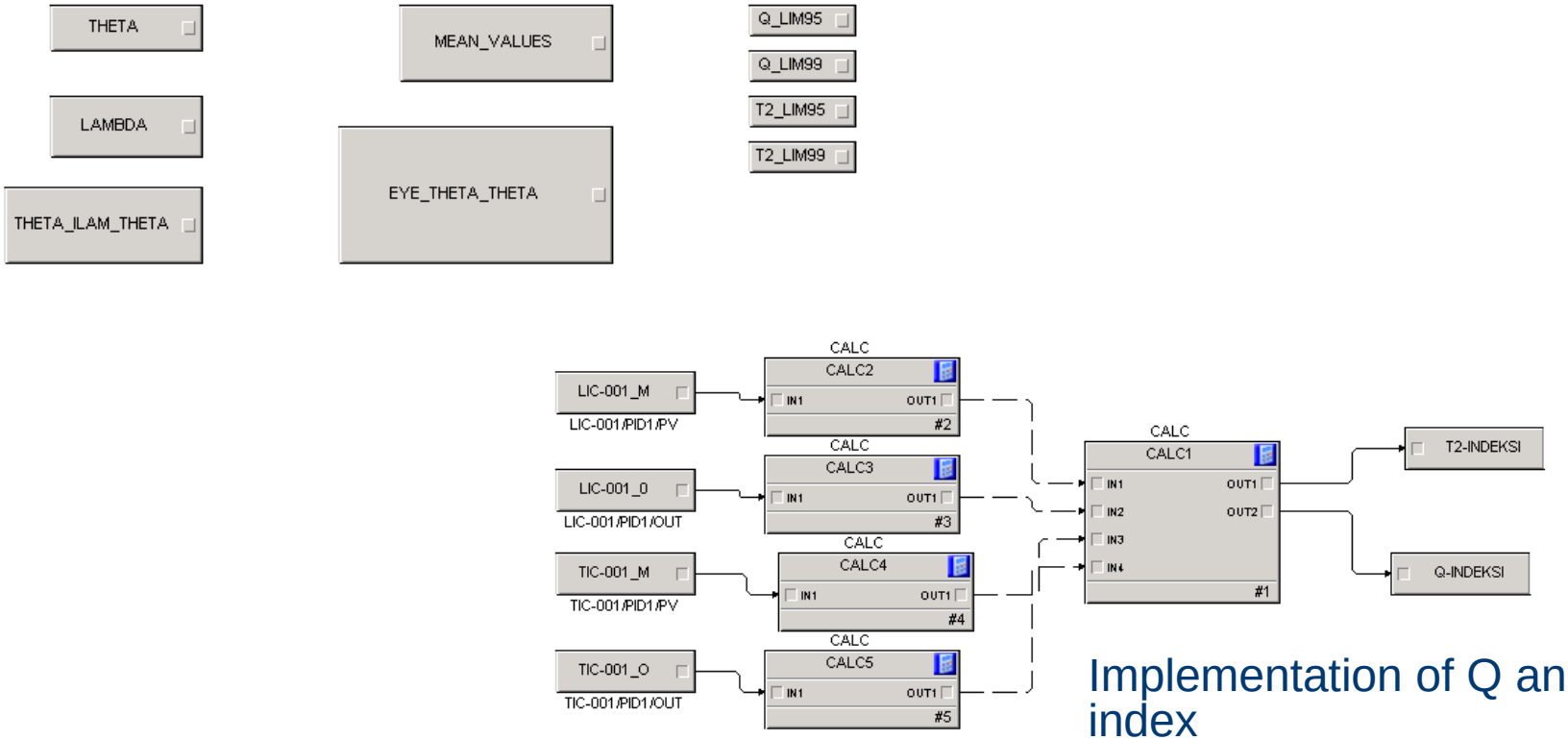
where c_α is the value of normal distribution with α level of significance

- Statistic T_α^2 can be calculated by means of the F- distribution as

$$T_\alpha^2 = [k\cdot(m-1)/m-k]\, F(k,m-1,\alpha)$$

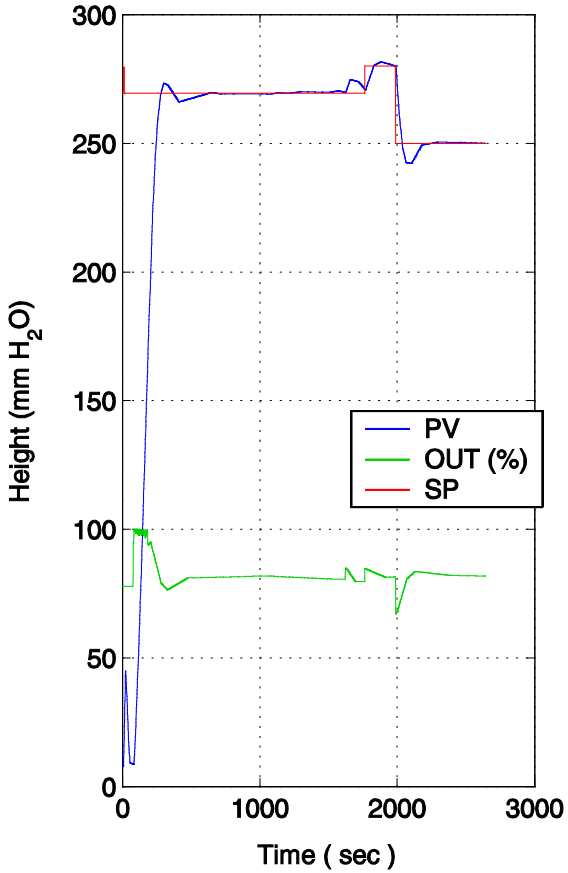
where F(k,m-1,α) is the upper 100 α% critical point of F-distribution witk k and m-1 degrees of freedom

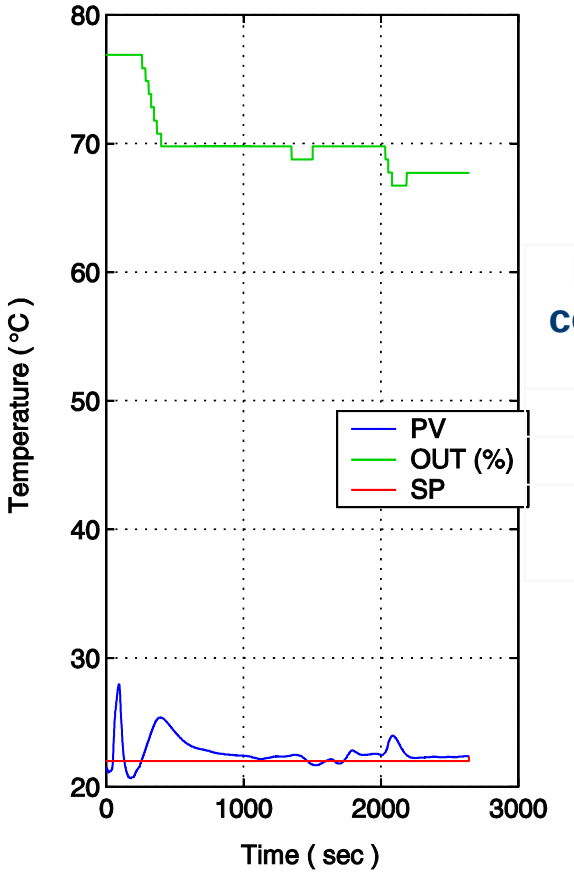
Implementation of Q and T^2 index in DeltaV automation system



Implementation of Q and T^2 index

Experiments and discussion: Level and temperature control in the first tank



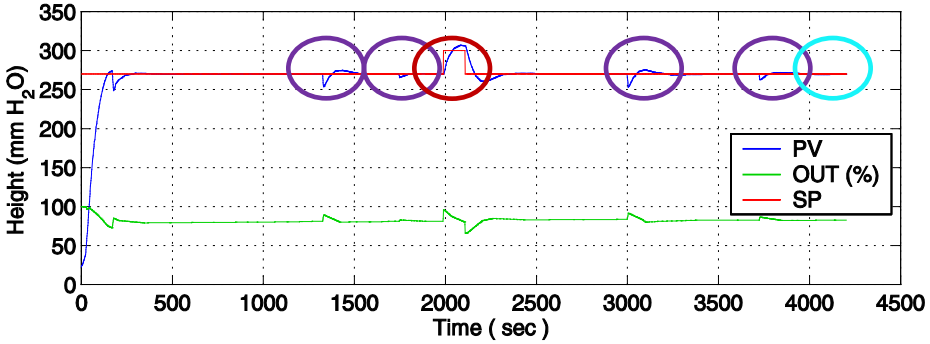


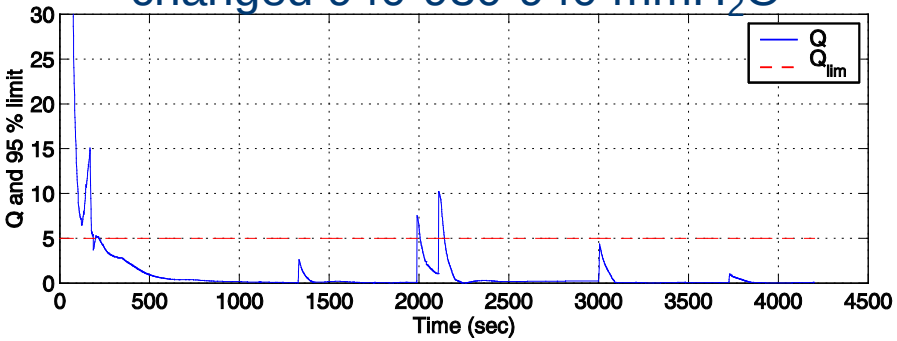
A set of 300 data samples

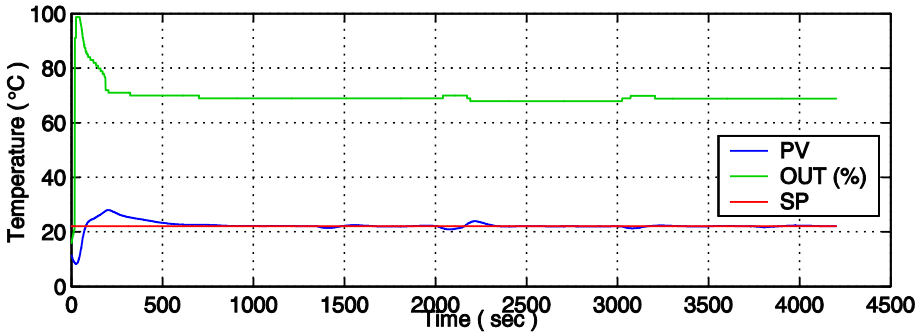
Principal component number	Variance	Total variance captured
1	0.5684	0.5684
2	0.3338	0.9023
3	0.3429	0.9880
4	0.0481	1

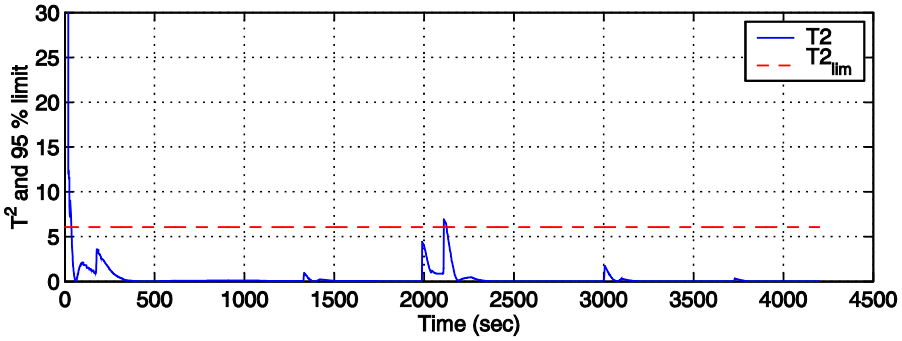
Experiments and discussion: Test data in the first tank and Q and T^2 statistics

- Bypass valve was opened 5, 1, 5 or 2 seconds
- Set point of the level (Tank 1) was changed 270-300-270 mmH_2O
- Set point of the level (Tank 2) was changed 940-930-940 mmH_2O









Conclusions

- Three tank system that was built to allow students and researchers to study control strategies
- Process monitoring system for the level and temperature of a mixing tank were investigated
- Principal component analysis (PCA) has been used to process monitoring
- Once the PCA model of a data set has been obtained, the process behaviour can be monitored with two variables, Q and T2 statistics
- Monitoring system is implemented in the DeltaV automation system

THANK YOU

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