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NONLINEAR ADAPTIVE CONTROL FOR CONTINUOUS STIRRED TANK REACTOR

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A Thesis Submitted in Partial Fulfillment of the Requirements  
for the Degree of Master of Engineering Program in Chemical Engineering

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พัชรางส์ สิริเชาวน์เลิศ : การควบคุมไม่เชิงเส้นแบบปรับตัวได้สำหรับเครื่องปฏิกรณ์แบบถังกวนต่อเนื่อง. (NONLINEAR ADAPTIVE CONTROL FOR CONTINUOUS STIRRED TANK REACTOR) อ. ที่ปรึกษา : รศ. ดร. ไพศาล กิตติสุภกร, 83 หน้า.

เครื่องปฏิกรณ์แบบถังกวนต่อเนื่องเป็นเครื่องปฏิกรณ์ที่ใช้กันอย่างแพร่หลายในกระบวนการอุตสาหกรรม ซึ่งจะมีความไม่เป็นเชิงเส้นสูงและมักแสดงพฤติกรรมที่ซับซ้อน ดังนั้นจึงยากต่อการควบคุมด้วยตัวควบคุมแบบเชิงเส้น ในงานวิจัยนี้ วิธีการควบคุมไม่เชิงเส้นแบบปรับตัวได้ถูกพัฒนาขึ้นโดยใช้การควบคุมแบบเจเนอริกโมเดลที่ค่าพารามิเตอร์ในการปรับจูนของตัวควบคุมมีการปรับค่าแบบออนไลน์ ร่วมกับกาลมานฟิลเตอร์แบบยี่ดขยายเพื่อกำหนดค่าพารามิเตอร์ที่ไม่ทราบค่าหรือมีความไม่แน่นอน

ประสิทธิภาพของตัวควบคุมที่ออกแบบในการควบคุมกระบวนการกรณีที่ถูกรบกวน และกรณีเกิดความผิดพลาดระหว่างแบบจำลองกับกระบวนการ จากผลการจำลองแสดงให้เห็นว่าการควบคุมไม่เชิงเส้นแบบปรับตัวได้ให้ประสิทธิภาพการควบคุมที่ดีทั้ง 2 กรณี และเมื่อเปรียบเทียบกับ การควบคุมแบบเจเนอริกโมเดลและพีไอดีพบว่า การควบคุมไม่เชิงเส้นแบบปรับตัวได้ให้ผลการควบคุมที่ดีกว่า

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PATCHARANG SIRICHAOVALERT : NONLINEAR ADAPTIVE CONTROL FOR CONTINUOUS STIRRED TANK REACTOR. THESIS ADVISOR: ASSOC. PROF. PAISAN KITTISUPAKORN, Ph.D., 83 pp.

A continuous stirred tank reactor (CSTR) is a type of reactors used commonly in industrial processing. It has inherently nonlinear and complex dynamic behavior and therefore it is difficult to handle with a linear controller. In this research, a nonlinear adaptive control approach is developed based on generic model control (GMC) with online adaptation of its tuning parameters. An extended Kalman filter has been incorporated to the control approach in order to determine unknown/uncertain parameters.

The performance of the designed controller has been evaluated in two cases: disturbance changes and plant/model mismatches. The simulation results have shown that the nonlinear adaptive control provides good control performance in both cases. Moreover, this controller is found to be better than the GMC and conventional Proportional Integral Derivative (PID) controller in all cases.

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## NOMENCLATURES

- $A_j$  = Heat transfer area ( $\text{m}^2$ )
- $b$  = *pseudo* reaction rate constant
- $C_i$  = Concentration of component  $i$  ( $\text{kmol}/\text{m}^3$ )
- $C_{i,0}$  = Initial concentration of component  $i$  ( $\text{kmol}/\text{m}^3$ )
- $C_{i,in}$  = Inlet concentration of component  $i$  ( $\text{kmol}/\text{m}^3$ )
- $C_{pi}$  = Heat capacity of component  $i$  ( $\text{kJ}/\text{kg K}$ )
- $C_{pj}$  = Heat capacity of jacket ( $\text{kJ}/\text{kg K}$ )
- $C_{pr}$  = Heat capacity of reactor ( $\text{kJ}/\text{kg K}$ )
- $E$  = Activity energy ( $\text{kJ}/\text{kmol}$ )
- $F_{i,in}$  = Molar flow rate of component  $i$  for the inlet stream ( $\text{kmol}/\text{s}$ )
- $k$  = Rate constant of reaction
- $K_1$  = Tuning parameter of GCM controller
- $K_2$  = Tuning parameter of GMC controller
- $P$  = Estimation error covariance matrix
- $q_{in}$  = Volumetric flow rate for the inlet stream ( $\text{m}^3/\text{s}$ )
- $q_j$  = Volumetric flow rate of jacket ( $\text{m}^3/\text{s}$ )
- $Q$  = Process noise covariance matrix

- $Q_r$  = Heat released by reaction (kJ/min)
- $Q_{re}$  = Estimated heat released by reaction (kJ/min)
- $R$  = Perfect-gas constant (kJ/kmol)
- $r_i$  = Rate of reaction
- $T_{in}$  = Inlet stream temperature for the startup (°C)
- $T_j$  = Jacket temperature (°C)
- $T_{jsp}$  = Jacket temperature set point (°C)
- $T_r$  = Reactor temperature (°C)
- $u$  = Manipulated input variable
- $U$  = Overall heat transfer in the jacket (kJ/(s m<sup>2</sup> °C))
- $V$  = Reactor volume (m<sup>3</sup>)
- $V_j$  = Jacket volume (m<sup>3</sup>)
- $y$  = Output of the process model

### GREEK LETTERS

- $\alpha$  = Pre-exponential factor from Arrhenius law (s<sup>-1</sup>)
- $\tau$  = Time constant
- $\tau_j$  = Time constant of jacket
- $\Delta H_r$  = Enthalpy of reaction (kJ/kmol)
- $\rho_{i,in}$  = Molar density of component  $i$  for the inlet stream (kmol/m<sup>3</sup>)



$\rho_j$  = Density of jacket ( $\text{kg/m}^3$ )

$\xi$  = Damping constant

### SUBSCRIPTS

$A$  = Propylene oxide

$B$  = Water+sulfuric acid

$C$  = Propylene glycol

$in$  = Inlet

$j$  = Jacket

$M$  = Methanol

$r$  = Reactor

$sp$  = Set point

$0$  = Initial

### ACRONYM

CSTR = Continuous stirred tank reactor

EKF = Extended Kalman filter

GMC = Generic model control

IAE = Integral absolute error

MRAC= Model reference adaptive control

STC = Self-tuning controller