SINGULARLY PERTURBATION METHOD FOR MULTIVARIABLE PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROLLER TUNING

MASHITAH BINTI CHE RAZALI

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Nama dan Alamat Pemeriksa Luar	:	**Prof. Madya Dr. Samsul Bahari bin Mohd Noor** **Jabatan Kejuruteraan Elektrik & Elektronik,** **Fakulti Kejuruteraan,** **Universiti Putra Malaysia,** **43400 Serdang, Selangor.**
Nama dan Alamat Pemeriksa Dalam I	:	**Prof. Madya Dr. Yahaya bin Md Sam** **Fakulti Kejuruteraan Elektrik,** **Universiti Teknologi Malaysia,** **81310 UTM Johor Bahru.**
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SINGULARLY PERTURBATION METHOD FOR MULTIVARIABLE PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROLLER TUNING

MASHITAH BINTI CHE RAZALI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

OCTOBER 2014

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I lovingly dedicate this thesis:

To my beloved husband who supported me each step of the way,
To my beloved mum who cheer me with endless support and enthusiasm,
To my beloved family and family in law who encourage me in everything,
To my beloved friends who helped a lot during finished this research.
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ABSTRACT

Efficient controls of industrial processes are of great importance. The industrial control performance has to be met with the desired optimum operation. However, the tuning process always becomes a challenging matter especially for Multiple-Input Multiple-Output (MIMO) system with two-time scale characteristic. This motivates the use of singularly perturbation method into the designs of Multivariable Proportional-Integral-Derivative (MPID) controller tuning. The singularly perturbation method based on Naidu and Jian Niu were considered and tested. It is observed that singularly perturbation system by Naidu method gives a good approximation at low, middle and high frequencies. Two MIMO systems with two-time scale characteristic, wastewater treatment plant and Newell and Lee evaporator were used as a test bed. Traditionally, the MPID controller tuning namely Davison, Penttinen-Koivo, Maciejowski and Combined are based on full order static matrix inverse model. In this work, the singularly perturbed MPID controller tuning methods were proposed based on the dynamic matric inverse to improve the tuning of the system. Furthermore, Particle Swarm Optimization has been applied in tuning the parameters for an optimum control performance. Comparing the closed loop performance and process interaction presented by the traditional MPID and singularly perturbed MPID controller methods, the latter method is able to improve the transient responses, provide low steady state error and reduce the process interaction.

ABSTRAK

Kawalan yang berkesan memainkan peranan yang sangat penting di dalam sesebuah proses industri. Prestasi kawalan bagi setiap industri hendaklah mencapai tahap operasi optimum yang diperlukan. Walau bagaimanapun, proses penalaan sering menjadi satu perkara yang mencabar terutamanya apabila melibatkan sistem yang mempunyai pembolehubah yang Berbilang-Input Berbilang-Output (MIMO) dengan ciri skala dua-kali. Ini mendorong kepada penggunaan kaedah usikan bersendirian ke dalam strategi mereka bentuk pengawal penalaan Pembolehubah Pelbagai Terbitan Penting Seimbang (MPID). Kaedah usikan bersendirian berdasarkan Naidu dan Jian Niu telah diguna dan diuji. Adalah diperhatikan bahawa kaedah usikan bersendirian oleh Naidu menawarkan anggaran yang baik pada frekuensi yang rendah, sederhana dan tinggi. Dua sistem MIMO dengan ciri skala dua-kali, iaitu loji rawatan air kumbahan dan penyejat Newell dan Lee telah digunakan untuk ujikaji. Pengawal penalaan tradisional MPID, Davison, Penttinen-Koivo, Maciejowski dan Combine adalah berdasarkan kepada model asal matrik statik songsang. Di sini, kaedah pengawal penalaan MPID usikan bersendirian berdasarkan matrik dinamik songsang telah dicadangkan bagi memperbaiki proses penalaan. Selain itu, Pengoptimuman Zarah Terkumpul telah diguna untuk mendapatkan parameter penalaan untuk kawalan yang optimum. Berdasarkan perbandingan bagi prestasi gelung tertutup dan proses interaksi di antara MPID tradisional dan MPID usikan bersendirian, kaedah yang kedua dapat meningkatkan tindak balas sementara, memberikan ralat keadaan mantap yang rendah dan mengurangkan proses interaksi.

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LIST OF ABBREVIATIONS

BIBO	-	Boundary Input Boundary Output
CLCP	-	Closed Loop Characteristic Polynomial
CMAES	-	Covariance Matrix Adaptation Evolutionary Strategy
CSTR	-	Continuously Stirred Tank Reactor
GA	-	Genetic Algorithm
IAE	-	Integral Absolute Error
IMC	-	Internal Model Control
ISE	-	Integral Squared Error
ITAE	-	Integral Time Weighted Absolute Error
ITSE	-	Integral Time Weighted Squared Error
I/O	-	Input/Output
LQG	-	Linear-Quadratic-Gaussian
MIMO	-	Multiple-Input Multiple-Output
MLSS	-	Mixed Liquor Suspended Solid
MPC	-	Model Predictive Controller
MPID	-	Multivariable PID
OLCP	-	Open Loop Characteristic Polynomial
ORSF	-	Order Real Schur Form
P	-	Proportional
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative
PRBS	-	Pseudo Random Binary Sequence
PSO	-	Particle Swarm Optimization

RGA	-	Relative Gain Array
RNGA	-	Relative Normalize Gain Array Concept
SGA	-	Successive Galerkin Approximation
SISO	-	Single-Input Single-Output
SPA	-	Singularly Perturbation Analysis
SPM	-	Singularly Perturbation Method
SPS	-	Singularly Perturbation System
WWTP	-	Wastewater Treatment Plant

LIST OF SYMBOLS

C_M	-	Controllable matrix
DO	-	Dissolved oxygen
D	-	Dilution rate
dB	-	Decibel
e_{ss}	-	Steady state error
F_2	-	Product flow rate
F_{200}	-	Cooling water flow rate
gbest	-	Global best
h	-	Hour
h^{-1}	-	Per hour
iter	-	Number of iteration
$iter_{max}$	-	Maximum number of iteration
K	-	Controller matrix
K_d	-	Derivative gain
K_i	-	Integral gain
K_P	-	Proportional gain
kg	-	Kilogram
kg/kPa	-	Kilogram per kilopascal
kg/m	-	Kilogram per meter
kg/min	-	Kilogram per minute
kW/K	-	Kilowatt per kelvin
kPa	-	Kilopascal
L_2	-	Separator level
m	-	Number of slow eigenvalue

M	-	Meters
mg/l	-	Milligrams per liters
mg^{-1}	-	Meters per gram
m^3/h	-	Meters cube per hour
N	-	Number of fast eigenvalue
Pbest	-	Particle's local best known position
P_c	-	Random probability
P_m	-	Mutation probability
P_2	-	Operating pressure
rad/s	-	Radius per seconds
r_1/ r_2	-	Random variable
S	-	Substrate
S	-	Seconds
Sec	-	Seconds
T	-	Time
T_r	-	Rise time
T_s	-	Settling time
W	-	Air flow rate
w	-	Inertia weigh
w_{max}	-	Maximum inertia weight
w_{min}	-	Minimum inertia weight
X	-	Biomass
X_r	-	Recycled biomass
α	-	Tuning parameter of Maciejowski method
φ	-	Tuning parameter of integral gain
ρ	-	Tuning parameter of proportional gain
δ	-	Tuning parameter of derivative gain
ω_B	-	Specific bandwidth frequency
%	-	Percent
% OS	-	Percentage overshoot
*	-	Unstable

LIST OF APPENDICES