Cairo University

STUDY OF SATELLITE MODEL ROBUSTNESS AND DESIGN OF A ROBUST ADAPTIVE CONTROL ALGORITHM

By

Mohamed Salah Shouman

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
AEROSPACE ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Under the Supervision of

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Thesis Title :

STUDY OF SATELLITE MODEL ROBUSTNESS AND DESIGN OF A ROBUST ADAPTIVE CONTROL ALGORITHM

Key Words :
Attitude Control, Sliding Mode Controller, Fuzzy Logic Controller, Robust Control, Robust Stability Theorems.

Summary :

The main objective of this thesis is to study the issues of robustness of satellite control subsystem under typical and newly developed control algorithms. It represents different algorithms of satellite attitude control and tests their robustness using robustness theories. It also calculates system sensitivity against unknown perturbations and uncertain parameters. The results of robustness theories and sensitivity calculations motivated the design of new adaptive robust control algorithm, which has high robustness and good performance. The algorithm consists of a combination between robust hybrid sliding mode controller and adaptive fuzzy logic controller.

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Lastly, I dedicate this thesis to my nation, hoping to be a candle that lights the road to a more glorious future, with honor and dignity.

Mohamed Shouman

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SYMBOLS:

c	Speed of Light ($3 * 10^8\ m/sec^2$)
C_D	Drag Coefficient
C_s	Surface Specular Reflection Coefficient
F_e	Solar Constant ($1367\ w/m^2$)
H	Angular Momentum, N.m.s
$\mathrm{I}_{n\times n}$	Unity Diagonal Matrix of Size n $\times$ n
J	Inertia Matrix, $Kg.m^2$
M	Torque, N.m
M_{aero}	Aerodynamic Moment Vector, N.m
M_{gg}	Gravity Gradient Moment Vector, N.m
M_{mag}	Magnetic Moment Vector, N.m
M_{sol}	Solar Radiation Moment Vector, N.m
ω_0	Spacecraft Orbital Angular Velocity, rad/sec.
Q	Attitude Quaternion, LQR Weighting individual state variables
q_v	Vector Part of The Quaternion.
q_0	Scalar Part of The Quaternion.
R	Position Vector, Weighting Individual Control Inputs
$R_\otimes$	Earth's Equatorial Radius Adopted for the IGRF ($= 6371.2m$)
T	Transformation Matrix
ϕ	Euler Angle Rotation about the Body x-axis (Roll angle)
$\phi(\mathrm{x}), \mathrm{x}\times$	Cross Matrix of Vector x.
θ	Euler Angle Rotation about the Body y-axis (Pitch angle)
ψ	Euler Angle Rotation about the Body z-axis (Yaw angle)
α	Rotation Angle
μ_E	Earth's Gravitational Constant ($= 3.986 \times 10^{14}\ m^3/s^2$)
$\|\ \ \|$	Euclidean Norm of Value.
$\|\ \ \|_2$	2-Norm of Value (Maximum singular value decomposition).
$\circ$	Quaternion Product
.	Dot Product Operation.

APPREVIATIONS:

ACS	Attitude control System
AFRSMC	Adaptive Fuzzy of Robust Sliding Mode Controller
BCS	Body Coordinate System.
NPDLC	Non-Linear PD-Like Controller

ICS	Inertial Coordinate System
IGRF	International Geomagnetic Reference Field
LQR	Linear Quadratic Regulator
LEO	Low Earth Orbit.
OCS	Orbital Coordinate System.
RSMC	Robust Sliding Mode Controller
SMC	Sliding Mode Controller
TOF	Total Output Feature (Performance Indicator Calculated from Control Objectives)

SUBSCRIPTS AND SUBERSCRIPTS:

B	Body Coordinate System
I	Inertial Coordinate System.
O	Orbital Coordinate System.

ABSTRACT

The main objective of this thesis is to study the issues of robustness of satellite control subsystem under typical and newly developed control algorithms. The typical control algorithms used in thesis are PD-Like controller, sliding mode controller and linear quadratic regulator. The thesis identifies and studies the sources of uncertainty in the model of the attitude control system. To assess robustness of the satellite model this work uses different robustness measurements such as Kharitonov's and Argoun's theorems as well as Patel and Toda's and Yedavalli results. It is found that the simulation results of sensitivity study and robustness analysis correspond in the sense that variations, which lead to less sensitivity, also result in better robustness. It also shown that the classical control algorithms applied to systems with nonlinear perturbations display low robustness and deteriorated performance, which is highly affected by perturbations. This motivated the design of new adaptive robust control algorithm, which has high robustness and good performance. The algorithm consists of a combination between robust hybrid sliding mode controller and adaptive fuzzy logic controller. Throughout the thesis, control parameters are optimized using Min-Max normalization algorithm.