

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Design of attitude determination and control system for
KIWISAT amateur satellite.**

A thesis presented in partial fulfillment of
the requirements for degree of

**Masters of Engineering
Mechatronics**

At

Massey University
Albany, Auckland
New Zealand

Abstract

This thesis is to present the design of “ADAC” system for “KiwiSat” cube satellite. An array of sensors were used: CMOS low resolution camera, sun sensor, earth horizon sensors, 3 axis magnetometer. The control of satellite rely on magnetic coils installed orthogonally to each other. Implementation of this system is essential to achieve the full control of the satellite when it reaches the lower orbit.

Solution for the pitfall such as: the lack of torque of the satellite when it’s parallel to the earth magnetic field, was also designed. Attitude estimation is nonlinear due of kinematics and the reading of above sensors.

Both a proportional-derivative controller and a linear quadratic regulator are implemented for control model of the system. And the Floquet Theory is used to check the stability of the controls, and an optimization method further optimizes the results.

Model was constructed by simulink program that was packaged with mathematical software called “Matlab”.

3D model of the satellite was drawn in SolidWorks for the purpose of visual interaction and behavior.

Acknowledgments

I would like to thank everyone who provided me with support and help in the time of this project.

Firstly I would like to thank my family: my dad Alex Makarov, my mum Elena Makarova and my little brother Dennis Makarov. They gave me great amount of support and faith in myself.

My sincere gratitude to my mentor Dr. Johan Potgieter at Institute of Technology & Engineering, Massey University, his understanding and guidance helped me through some rough stages of my Masters project. His great knowledge have been a huge amount of help to me.

My gratitude and thanks to my supervisors: Fred Kennedy and Jonathan Henderson. For their detailed structural comments and amount of help they provided.

Also I would like to thank all staff members who helped me to achieve completion on my practical part of the project.

And a big thanks to my university friends, who provided a big moral support.

Without all of you, it wouldn't be possible! Thank you guys!

Table of Contents

Chapter:

1. Introduction	1
1.1. Objectives	1
1.2. Literature overview	1
1.2.1. Magnetic field	1
1.2.2. Earth magnetic field	4
1.2.3. Spacecraft magnetic field	13
1.2.4. Literature review discussion	22
2. ADAC system for magnetically controlled satellites	23
2.1. Dynamics and Attitude determination	23
2.1.1. Spacecraft and orbit dynamics	23
2.1.2. Attitude dynamics	32
2.1.3. Attitude determination	39
2.2. Control of satellite	40
2.2.1. Control and stabilization	40
2.2.2. Control laws	41
3. Model and results	45
3.1. Mathematical model of the system	45
3.2. Animation	53
3.3. Results	56
4. Discussion and conclusion	62
4.1. Discussion	62
4.2. Conclusion	62
References	63

Appendix

LIST OF TABLES, FIGURES AND GRAPHS

Figure 1.1: Magnetic field of the bar magnet	3
Figure 1.2: Magnetic field Units	4
Figure 1.3: Magnetic field Strengths	5
Figure 1.4: Magnetic field model	6
Figure 1.5: Geomagnetic Coordinates	6
Figure 1.6: The Magnetosphere	7
Figure 1.7: Appearance and Evolution of a Magnetic wave	11
Figure 1.8: Movement of the North Pole over Time	12
Figure 1.9: Movement of the South Pole over Time	12
Figure 1.10: Forces on the Moving Charges in a Current-Carrying Conductor	13
Figure 1.11: Forces on a Current-Carrying Loop in a Magnetic	15
Figure 1.12: Magnetic Torque Direction	18
Figure 1.13: Magnetic control torque	19
Figure 1.14: Equatorial Orbit in Magnetic field	21
Figure 1.15: polar orbit in Magnetic Field	22
Figure 2.1: Relative Motion of Two Bodies	25
Figure 2.2: Values of eccentricity and Elliptical orbit	27- 28
Figure 2.3: Orbital Elements	28
Figure 2.4: Heliocentric-Ecliptic Coordinate System	30
Figure 2.5: Earth-Centered Inertial reference Frame	31
Figure 2.6: Earth-Centered Earth-Fixed Reference Frame	32
Figure 2.7: Earth-Centered Inertial and Orbital Reference Frame	33

Figure 2.8: Ranges of sensor Accuracy	39
Figure 2.9: Summary of LQR Method	44
Figure 3.1: Designed dynamics system of amateur satellite	45
Figure 3.2: The simulation model	46
Figure 3.3: Attitude determination and control box	46
Figure 3.4: Embedded Block Diagram	47
Figure 3.5: Angular velocity stabilization.....	48
Figure 3.6: Behavior of satellite	49
Figure 3.7: Attitude matrix	50
Figure 3.8: 3D model of the satellite	53
Figure 3.9: Quaternions with No Magnetic Torque, Initial Angle=14	57
Figure 3.10: Quaternions with No Magnetic Torque, Initial Angle=6	58
Figure 3.11: Quaternion for P-D Controller with assigned gains	59
Figure 3.12: Eigenvalues of $X(t)$	60
Figure 3.13: Quaternion for Linear, LQR Controller	60
Figure 3.14: Magnetic Moment	61

LIST OF SYMBOLS

H - Magnetic field of a bar magnet

r - Distance between the magnetic field source and the measurement point

\hat{a}_r - Unit vector from the center of the magnet to the measurement point

M - Magnetic dipole moment of the bar magnet

\mathcal{M} - Magnetization

B - Flux density

μ_0 - Magnetization and the permeability of free space

R_{\oplus} - Radius of the Earth

F - Force

q_1, q_2 - Electrical charges

v_1, v_2 - Drift velocity of the positive charge

n_i - Number of positive charges

A_w - Cross-sectional area of the wire

l_w - Length of the wire

J - Current density

I - Current

B_k - Component of the field which is parallel to the wire

N - Number of turns of wire

μ - Permeability of the core material

\hat{n} - Unit vector normal to plane of the coil

Δg_m - Undesired magnetic torque

\hat{B} - Unit vector in the direction of the magnetic field

m - Mass of the object

$\Sigma \mathbf{F}$ - vector sum of the forces acting on mass of the object

$\ddot{\mathbf{r}}$ - Vector acceleration of **m**

G - Universal gravitational constant with a value of $6.670 \times 10^{-11} \text{m}^3/(\text{kg}\cdot\text{s}^2)$

μ - Gravitational parameter

h - Angular momentum

ϕ_f - Flight path angle

p - Semilatus parameter

e - Eccentricity

a - Semi-major axis

I - Inclination (chapter 2)

Ω - Right ascension of the ascending node

ω - Argument of periapsis

T - Time of periapsis passage

Π - Longitude of periapsis

v_0 - True anomaly at epoch

t_0 - Particular epoch

u_0 - Latitude at epoch

l_0 - The true longitude at epochs