UNIVERSITI PUTRA MALAYSIA

OPTIMUM SPACECRAFT ATTITUDE CONTROL METHODS FOR A COMBINED ATTITUDE AND THERMAL CONTROL SYSTEM

M. SALEH BASHA AL-KHODARI

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BY

M. SALEH BASHA AL-KHODARI

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Supervisor: Associate Professor Renuganth Varatharajoo, PhD

Faculty: Engineering

Spacecraft missions need efficient and precise attitude control systems. With the aim of reducing the vehicle volume and mass, and for a greater reliability, a system combining the conventional spacecraft attitude control and thermal control systems in a single system is proposed. The combined attitude and thermal control system (CATCS), which can work as an attitude actuator and as a heat pipe, uses the satellite's excess heat to circulate an electric conductivity fluid in a circular closed duct. The fluid circulation provides an angular momentum that can be used for spacecraft attitude controls.

The CATCS system is a maiden solution that combines both the attitude and thermal control systems. The feasibility of CATCS has been demonstrated in a previous

study. However, the demonstration is dedicated to a single axis (pitch) attitude control capability using the proportional-integral (PI) controller.

The proposed work focuses on improving the performance of the attitude control of LEO small satellites with the CATCS system as an actuator by applying a number of advanced control methods. The thermal control performances and properties are constant as in Ref. (Varatharajoo et al., 2003). In addition, there will be no thermal control degradation. A mathematical model of the satellite is represented based on the assumption that the satellite is a rigid body. First, the classical PI controller has been used for a 3-axis attitude control (roll, pitch and yaw). Then, four advanced control methods have been designed and tested to improve the attitude control performance of a small satellite using the CATCS system. The advanced controllers are: the Active Force Control (AFC) with PI controller (AFC-PI), H_2 controller, H_∞ controller, and the mixed H_2/H_∞ controller. The proposed controllers are designed to keep the attitude accuracy below the 0.2°. The controllers were applied to a 3-axis satellite attitude control independently. The controllers together with their governing equations are coded in MATLAB™ and SIMULINK® for both ideal and non-ideal system numerical simulations.

The analysis of the results shows that the H_2 controller gives the best attitude control performance compared to the other tested controllers, while the PI controller gives the worst attitude control performance for the reference case. The AFC-PI controller shows much better responses than the solely PI controller. The mixed H_2/H_∞ control shows good attitude accuracies, while the H_∞ control has low attitude accuracies compared to the other advanced controllers. The control gains of the designed

controllers are small and reasonable except that of the H_∞ controller. However, from the performance figures, it is clear that all the proposed controllers can efficiently provide a full 3-axis control with attitudes accuracies below 0.2°. The attitude performances show that the CATCS attitude pointing accuracy can be improved through the proposed advanced control methods.

Abstrak projek yang dikemukakan kepada Senat universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KAEDAH PENGAWALAN ATITUD KAPAL ANGKASA OPTIMUM UNTUK SISTEM GABUNGAN KAWALAN ATITUD DAN TERMA

Oleh

M. SALEH BASHA AL-KHODARI

Februari 2011

Penyelia: Profesor Madya Renuganth Varatharajoo, PhD

Fakulti: Kejuruteraan

Misi atau tugasan kapal angkasa lepas memerlukan sistem kawalan pengendalian yang cekap dan tepat. Untuk mengurangkan muatan dan jisim pesawat, dan untuk keandalan yang lebih baik, satu sistem yang menggabungkan sistem kawalan pengendalian kapal angkasa dan sistem kawalan haba telah dibangunkan. Sistem kawalan gabungan ini (CATCS), yang boleh berfungsi sebagai penjana kendalian dan paip haba, menggunakan lebihan haba daripada satelit untuk mengalirkan cecair pembawa elektrik dalam satu lingkaran yang bertutup. Pengaliran cecair ini membekalkan pusaran yang boleh digunakan untuk kawalan pengendalian kapal angkasa lepas.

Sistem CATCS ini adalah satu cara penyelesaian pertama yang menggabungkan kedua-dua sistem kawalan pengendalian dan kawalan haba. Kebolehan CATCS telah ditunjukkan dalam satu kajian terdahulu. Walaupun demikian, demonstrasi tersebut hanya ditujukan kepada kemampuan kawalan pengendalian satu paksi (yang ditegakkan) dengan menggunakan pengawal yang berkadar integral (PI).

Dalam kajian ini, satu model matematik pada satelit telah diperkembangkan, dengan berasaskan kepada andaian bahawa satelit tersebut adalah satu jisim yang tetap. Di sini, pengawal telah digunakan untuk kawalan tiga paksi dan empat lagi kaedah kawalan yang lebih moden telah direkacipta dan diuji untuk memperbaiki prestasi kawalan pengendalian satelit yang kecil menggunakan sistem CATCS. Kawalan berkenaan ialah: kawalan PI (AFC-PI), dan H_2, H_∞, dan campuran strategi kawalan H_2/H_∞. Kesemua kawalan ini telah diaplikasikan kepada kawalan secara bebas pengendalian tiga paksi satelit dan telah dibandingkan dalam pelbagai simulasi menggunakan MATLAB™ dan SIMULINK® bagi kedua-dua model sistem yang idial dan tidak idial.

Analisis dari hasil kajian telah menunjukkan bahawa pengawal H_2 memberikan prestasi kawalan pengendalian yang terbaik berbanding dengan kawalan lain yang diuji, sementara kawalan PI menunjukkan prestasi kawalan yang paling lemah untuk ciri-ciri satelit yang telah dipilih. Kawalan AFC-PI menunjukkan maklumbalas yang lebih baik daripada kawalan PI. Kawalan campuran H_2/H_∞ menunjukkan ketepatan maklumbalas yang baik, sementara kawalan H_∞ mempunyai nilai ketepatan yang rendah berbanding dengan kawalan lain tetapi lebih baik dari kawalan PI. Selain itu, penggunaan kuasa pengawal juga didapati sangat tinggi di dalam kes kawalan

pengawal H_∞. Walaubagaimanapun, daripada statistik prestasi, jelaslah bahawa kawalan yang dicadangkan mampu mengawal pengendalian tiga-paksi satelit dengan efisien, di mana ketepatan pengendalian yang diperolehi adalah $< 0.2^\circ$. Prestasi pengendalian yang didapati menunjukkan bahawa sistem CATCS mampu menjalankan kawalan pengendalian tiga paksi satelit.

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I certify that an Examination Committee met on 23/2/2011 to conduct the final examination of M. Saleh Basha Alkhodari on his Doctor of Philosophy thesis entitled "Optimum Spacecraft Attitude Control Methods for A Combined Attitude and Thermal Control System" in accordance with Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee are as follows:

Abdul Aziz B. Jaafar, PhD
Aerospace Department
Faculty of Engineering,
Universiti Putra Malaysia
(Chairman)

Harijono Djojodihardjo, PhD
Professor
Aerospace Department
Faculty of Engineering,
Universiti Putra Malaysia
(Internal Examiner)

Samsul Bahari B. Mohd. Noor, PhD
Department of Electrical & Electronics Engineering,
Faculty of Engineering,
University Putra Malaysia,
(Internal Examiner)

Michael Yu. Ovchinnikov, PhD
Professor
Keldysh Institute of Applied Mathematics,
Russian Academy of Sciences,
Moscow, Russia**.**
(External Examiner)

BUJANG KIM HUAT, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 23 February 2011

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment on the requirement for the degree of Doctor of Philosophy. The members of the supervisory committee were as follows:

Renuganth Varatharajoo, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Shah Nor b. Basri, PhD, F.A.Sc.
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohd Ramly b. Mohd Ajir
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

_____
HASANAH MOHD GHAZALI, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

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M. SALEH BASHA AL- KHODARI

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