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On spacecraft maneuvers control subject to propellant engine modes

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ABSTRACT

The paper attempts to address a new control approach to spacecraft maneuvers based upon the modes of propellant engine. A realization of control strategy is now presented in engine on mode (high thrusts as well as further low thrusts), which is related to small angle maneuvers and engine off mode (specified low thrusts), which is also related to large angle maneuvers. There is currently a coarse-fine tuning in engine on mode. It is shown that the process of handling the angular velocities are finalized via rate feedback system in engine modes, where the angular rotations are controlled through quaternion based control (QBCL)strategy in engine off mode and these ones are also controlled through an optimum PID (OPIDH) strategy in engine on mode.

1. Introduction

The process of orbital transferring is now known as one of important issues in the area of spacecraft control. It aims the spacecraft to transfer from the initial orbit to its final ones with a focus on small angle maneuvers. The idea, presented here, attempts to suggest a new approach in this field through a hybrid three-axis attitude control strategy for the purpose of designing spacecraft maneuvers control, namely SPCMAC. In this way, the finite-time control strategy is organized in both modes of engine on and off. It should be noted that the engine on mode is useful to start transferring in finite burn, as coarse tuning. And the engine off mode is suitable to complete the process, as fine tuning, in a finite amount of time. It is proposed that two sets of thrusters need to be dealt with through the proposed control strategy in association with the decision maker system. The first set of thrusters is related to high thrusts and a number of further low thrusts in engine on mode. The second set of thrusters is related to low thrusts in engine off mode, as well. The realization of control strategy is based on the inner and the corresponding outer closed loops in both modes. The responsibility of the decision maker system is to manage the information regarding the coarse-fine tuning in engine on mode. It manes that coarse tuning is dealt with, at first, and after that fine tuning is also used to present an accurate pointing process. The inner closed loops are organized in line with the rate feedback systems and the outer closed loops are organized in line with the optimum PID scheme, which is designed through an optimization procedure. It is useful to find the present control scheme, in its optimum coefficients, to deal with small angle maneuvers. Moreover, in engine off mode, which is related to large angle maneuvers, the quaternion based control scheme is realized to deal with maneuvers. It is apparent that the inner closed loops are to deal with the angular velocities in the three axes, while the outer closed loops are to cope with the angular rotations in the three axes. There are currently a set of pulse-width pulse-frequencies (PWPFs) and control allocations (CAs), while the inner closed loops have PWPF modulators to be able to handle a number of on–off high–low thrusters, while CA is realized to assist in the process of coping with in the present overactuated system.

Regarding the background of the research presented here, it should be noted that during the past decades, a number of efficient and applicable studies on the spacecraft attitude control have been carried out. With a focus on the recent potential outcomes in the spacecraft maneuvers control, McCamish et al. describe autonomous distributed control by suggesting the control

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efforts in the linear quadratic regulator in association with the robust collision avoidance capability for the artificial potential function [1]. Pukdeboon et al. suggest high order sliding mode control approaches for spacecraft attitude maneuvers by considering a class of linear sliding manifolds that is selected as a function of angular velocities and quaternion errors [2]. Scharf et al. present flight-like ground demonstrations of maneuvers for spacecraft in two parts. The first results are related to the formation control architecture and synchronized rotation guidance algorithm, which are used in the formation flying demonstrations and the second outcomes are related to the experimental results for these demonstrations [3,4].

Leigh et al. describe a navigation solution to a maneuver of spacecraft relative to satellites and ground locations. There is a dynamic differential correction algorithm to deliver an impulsive maneuver for a satellite, in order to place it within overlapping spheres [5]. Zhang et al. reveal integrated translational and rotational finite-time maneuver with its application to a rigid spacecraft under actuator misalignment, where the strategy is proposed via terminal sliding mode technique. It is realized to enable the spacecraft for tracking the command position and attitude in a pre-determined time [6]. Maclean et al. suggest repointing maneuvers for nano-spacecraft to be generated by optimizing the free parameters of the analytical expressions and the initial angular velocities in the attitude of the spacecraft [7]. Li et al. propose maneuver-aided active satellite tracking via six degree-of-freedom optimal dynamic inversion control. There are tracking approach and osculating-orbit based coordinate matching scheme regarding the tracking attitude [8].

With a focus on the attitude control realization of the spacecrafts, Sabatini et al. propose a method for delay compensation, while Zheng et al. suggest an autonomous attitude coordinated control [9,10]. Yang et al. propose nonlinear attitude tracking control for spacecraft. They have tried to deal with the attitude tracking control with communication delays [11]. Huo et al. suggest finite-time fault tolerant attitude stabilization control for rigid spacecraft. In this work, a sliding mode control scheme is proposed to solve the problem of attitude stabilization [12]. In the Du et al. research, an attitude synchronization control for a class of flexible spacecraft is proposed to solve the problem of attitude. Using the backstepping realization in association with the neighbor based rules, a distributed attitude control law is suggested [13]. Song et al. work is to realize finite-time control for nonlinear spacecraft attitude via terminal sliding mode strategy [14]. Lu et al. research is to deal with an adaptive attitude tracking control for rigid spacecraft with finite-time convergence. In this research work, the attitude tracking control problem is addressed for rigid spacecraft with external disturbances and inertia uncertainties [15]. Yang at al. review spacecraft attitude determination and control using the quaternion based methods. In this review, these quaternion based methods are first discussed for spacecraft attitude determination and control [16]. Zou et al. work is presented an adaptive fuzzy fault-tolerant attitude control of spacecraft. They investigate the attitude control, since unknown mass moment of inertia matrix, external disturbances, actuator failures and input constraints are all existed [17].

Hu et al. work is to realize robust attitude control for spacecraft under assigned velocity and control constraints, while Cai et al. work is to deal with the leader-following attitude control of multiple rigid spacecrafts [18,19]. Hereinafter, Kuo et al. work is presented in attitude dynamics and control of miniature spacecraft via pseudo-wheels and Zhang et al. research is given in attitude control of rigid spacecraft with disturbance generated by time varying exo-systems [20,21]. Erdong et al. propose robust decentralized attitude coordination control of spacecraft formation, where Bustan et al. work is in robust fault-tolerant tracking control design under control input saturation [22,23]. Lu et al. have proposed a design of control strategy for rigid spacecraft attitude tracking with actuator saturation, while Pukdeboon et al. have suggested an optimal sliding mode controllers for attitude tracking of spacecraft via Lyapunov function [24,25]. Afterwards, time-varying sliding mode controls in the area of rigid spacecraft attitude tracking is presented by Yongqiang et al., while adaptive sliding mode control with its application to six degree-of-freedom regarding the motion of spacecraft under input constraint is given by Wu et al. [26,27]. Furthermore, adaptive backstepping fault-tolerant control for flexible spacecraft under unknown bounded disturbances as well as actuator failures is presented by Jiang, as long as the realization of attitude control of spacecraft is presented by Butyrin et al. And relative position finite-time coordinated tracking control for the spacecraft formation without velocity measurements is presented by Hu, as well [28–30]. With a focus on double feedback control loop, Vijayan et al. suggest the design of the PID control approaches in double feedback loops under set-point filters. And with a focus on the control coefficients tuning, Besançon-Voda presents iterative auto-calibration of digital controllers, where Precup et al. suggest PI and PID control approaches tuning for integral-type servo systems, in order to ensure robust stability and robustness [31–33]. Ginter et al. propose robust gain scheduled control in the area of a hydrokinetic turbine, while Jin et al. suggest the realization of the internal model control in association with the PID based model matching approach as well as closed-loop shaping [34,35].

Regarding the PWPF research, there are various literatures in this area, where the best one may be related to Krovel. It describes the optimal tuning of the PWPF modulator in the attitude control, in a constructive manner, where Sidi presents its main idea in the spacecraft dynamics and control, as a practical engineering approach [36,37].

Regarding the control allocation research, Johansen et al. survey this issue to be addressed. The subject of control allocation can suggest the advantage of a modular design, as long as the high-level motion control algorithm is designed [38]. Zaccarian has proposed dynamic allocation for input redundant control systems. It is proposed to address control systems under redundant actuators, where the concepts of weak and strong input redundancy are characterized [39]. Servidia research is to deal with control allocation for gimbaled/fixed thrusters. There are some overactuated control systems, which are using a control distribution law between the controllers and the actuators [40].

The whole of above-referenced outcomes are tried to address some efficient solutions to deal with the present complicated system. In the same way, the proposed SPCMAC strategy has investigated another solution in this area, while the necessity of proposing the approach is to handle the new control strategy in its competitive results with respect to other considered ones. In fact, the novelty of the approach presented here is to suggest a control strategy, which is able to drive the orbital transferring and also the precise pointing processes regarding the spacecraft. They can briefly be listed as follows: (i) the proposed control strategy is designed to enable both engine on–off modes, which are directly related to the small and the large angles maneuvers that are important to reach the reliable missions. It should be noted that the mechanism of dealing with the present engine modes is based upon the thruster's configuration, which is solely investigated in this research. In fact, the physical configuration of the thrusters is novel to enable a number of thrusters, in a simultaneous manner that is able to deal with both engine on–off modes. (ii) The present double closed loop control approach is realized to deal with the angular rotations through a new quaternion based control (QBC_L) strategy, in engine off mode. And the corresponding angular velocities are dealt with through an optimum PID ($OPID_H$) strategy,