第 31 回　アストロダイナミクスシンポジウム（2021 年）アブストラクト集
31st Workshop on JAXA Astrodynamics and Flight mechanics (2021) Abstract

Special Lecture Jul 26th(Mon) Main Room PM(12:30-13:10)

横小路泰義先生(Prof. YOKOKOHJI Yasuyoshi)
神戸大学大学院工学研究科機械工学専攻(Department of Mechanical Engineering, Graduate School of Engineering, Kobe University)

「テレオペレーションの過去，現在，未来」
「Past, Present, and Future of Teleoperation」

Abstract
ロボットの遠隔操縦は，ロボット工学の前身となる歴史ある技術ですが，ロボット工学の進展とともに発展しつつ今でも様々な分野に応用されています．本講演では，この遠隔操縦技術の歴史を理論面と応用面から振り返り，未来の展望につなげたいと思います．
Robot teleoperation is a historical technology that was the predecessor of robotics, but it is still being applied to various fields while developing along with the progress of robotics. In this lecture, I would like to review the history of this teleoperation technology from both theoretical and application aspects and connect it to the future perspective.

Special Lecture Jul 27th(Tue) Main Room PM(12:30-13:10)

山田哲哉先生（Prof. YAMADA Tetsuya）
宇宙航空研究開発機構　宇宙科学研究所（ISAS/JAXA）

「はやぶさ 2 サンプル回収カプセル：再突入飛行とその回収」
「Hayabusa2 Sample Return Capsule : Reentry Flight and Recovery Operation」

Abstract
After successful exploration on the Asteroid Ryugu, Hayabusa2 spacecraft(S/C) returned to the earth in the beginning of Dec. 2020. The sample return capsule (SRC) were separated from S/C and entered the earth atmosphere with a velocity of 12 km/s. Passing through a severe aerodynamic heating corridor, SRC deployed a parachute at an estimated altitude of 10km and slowly landed on the ground. All the SRC components together with asteroid samples were safely recovered within the day. The special lecture outlines the reentry flight of SRC and the recovery operation.

Jul 26th(Mon) Room A AM(9:30-12:00)　Abstracts

ASTRO-2021-A001

「サロゲートモデルを用いた小惑星マルチフライバイの大域的軌道最適化に関する研究」

「Surrogate-Assisted Global Trajectory Optimization For Multiple Asteroid Flyby Missions Utilizing Earth Gravity Assists」

* 尾崎 直哉(JAXA ISAS), 柳田 幹太(東大・院), プシュパラジ ニシャント(総研大・院), 近澤 拓弥(東大・院), 兵頭 龍樹(JAXA ISAS)

Abstract:

Global trajectory optimization problems with multiple flybys are formulated as two nested optimization problems: an inner loop optimizes the trajectory for a given flyby sequence, and an outer loop chooses the sequence of the flybys. As the number of flyby bodies grows, the computation time of the optimization problems expands maliciously. Recent studies have presented that introducing a surrogate model that approximates the inner loop cost reduces the total computational effort. This paper proposes a surrogate-assisted global trajectory optimization method for multiple asteroid flyby missions utilizing multiple gravity assists. The application to JAXA's DESTINY+ mission shows that the proposed method efficiently searches the globally optimized trajectory that explores Phaethon and some other asteroids within the lifetime.

ASTRO-2021-A002

「超小型探査機 EQUULEUS の軌道設計手法とその設計状況」

「Trajectory design resutls for 6U CubeSat EQUULEUS」

* 川端 洋輔(東大), デイ トス ディオジェネ(JAXA), 近澤 拓弥, 柿原 浩太(東大・院), 船瀬 龍(東大/JAXA)

Abstract:

EQUULEUS (EQUilibriUm Lunar-Earth point 6U Spacecraft) is a 6U CubeSat which is being developed by the University of Tokyo and the Japan Aerospace Exploration Agency (JAXA). EQUULEUS will be launched at the end of 2021　by NASA's Space Launch System rocket as a piggyback and transfer to an Earth-Moon L2 (EML2) quasi-Halo orbit via invariant manifolds and lunar flybys. We present EQUULEUS trajectory design method and its latest trajectory design results.

ASTRO-2021-A003

「ソーラーセイルによる地球-月系 NRHO から太陽-地球系ハロー軌道への遷移軌道設計」

「Transfer Trajectory from Earth-Moon NRHO to Sun-Earth Halo Orbit by Solar Sails」

* 中条 俊大(東工大), 高尾 勇輝(JAXA), 大島 健太(広工大)

Abstract:

Lunar Orbital Platform Gateway is expected to provide opportunities for micro probes or CubeSats to be released from the Earth-Moon 9:2 synodic NRHO. We investigate usefullness of solar sails released there to fly in the Sun-Earth-Moon system, and show that using solar radiation pressure for propulsion drastically reduces the necessary amount of delta-V in low-energy transfer trajectries.

ASTRO-2021-A004

「平面円制限四体問題におけるソーラーセイルの地球-月系 L1/L2 周りの周期軌道」

「Earth-Moon Libration Point Orbits of Solar Sails in Bicircular Restricted Four Body Problem」

* 中条 俊大(東工大), 高尾 勇輝(JAXA)

Abstract:

Solar sails provide propellant-free propulsion for orbit control, which can be applied to station keeping of Sun-Earth libration point orbits. However, it is usually difficult for solar sails to maintain Earth-Moon libration point orbits because the direction of the sun dynamically changes, and variation of the tidal force and solar radiation pressure along the orbital motion becomes perturbation over the capability of photon propulsion. Therefore, we includede the perturbation of due to the sun in the design of reference orbits so that it can be maintained by solar sails, which eventually become synodic resonant orbits.

ASTRO-2021-A005

「光子加速・電気推進ハイブリッドシステム用いた惑星間ミッションにおける軌道設計」

「Trajectory Design of Interplanetary Missions with Hybrid Solar Electric-Photonic Propulsion」

* 高尾 勇輝（JAXA), 中条 俊大（東工大）

Abstract:

This paper presents interplanetary trajectories accomplished by the hybrid use of solar electric propulsion (SEP) and solar sailing. This concept enables a propulsion system with greater thrust and better fuel efficiency than conventional means. Making use of solar photonic assists at

perihelion and deep space maneuvers by SEP at aphelion, a faster travel to the outer solar system becomes possible. In this study, an interplanetary mission by a 12U-class micro solar power sail deployed in a cislunar orbit is presented. To handle this, a systematic method for preliminary trajectory design is developed.

Jul 26th(Mon) Room A PM1(13:30-15:30)　Abstracts

ASTRO-2021-A006

「OMOTENASHI 探査機の消費電力制限を考慮した姿勢軌道制御」

「Attitude and orbit control of OMOTENASHI spacecraft considering power constraints」

* 橋本 樹明(JAXA)

Abstract:

OMOTENASHI spacecraft has very strict power constraints, both instantaneous power and battery capacity. Considering those constraints, an attitude and orbit control scheme during orbit maneuver was developed. That is, torque commands to the reaction wheels are limited during the thrusters are used. When attitude error exceeds the threshold, the propulsion heaters are switched off and the torque command limit becomes nominal. If the battery voltage decreases below the limit, attitude maneuver to a sun point attitude is conducted automatically. In the presentation, outline of the control scheme and some test results using a simulator are reported.

ASTRO-2021-A007

「OMOTENASHI 月面着陸用固体ロケットモータ点火最適時刻の決定方法」

「Method for Determining the Optimal Ignition Time of a Solid Rocket Motor for Lunar Landing of OMOTENASHI」

* 森下 直樹, 橋本 樹明(JAXA)

Abstract:

OMOTENASHI is the world's smallest spacecraft that will attempt to land on the Moon. In the landing sequence, the surface probe, a landing module, is decelerated by a retro-thrust super-small solid rocket motor. Here, since OMOTENASHI takes a trajectory where the flight path angle is about 90 degrees and its initial speed is about 2500 m/s, the timing of the ignition is critical for a successful landing. In this presentation, we will discuss our study on the optimal ignition timing for the super-small rocket motor of OMOTENASHI.

ASTRO-2021-A008

「OMOTENASHI プロジェクトの SCLT シミュレータ開発」

「Development of SCLT simulator for OMOTENAHSI project」

* 坂東 信尚, 平澤 遼, 森下 直樹, 橋本 樹明(JAXA)

Abstract:

OMOTENASHI(Outstanding Moon exploration TEchnologies demonstrated by NAno Semi-Hard Impactor) will be launched by the SLS rocket in 2021. The flight software of OMOTENASHI was completed by In-house process with software manufacturer support. In the part of the flight software, there are several operations depending on the explorer's behavior. To verify these operations, SCLT simulator has to be developed with simulating the explorer's dynamics and the interface between the on-board computer. In this paper, the SCLT simulator for OMOTENAHSI project is introduced. In addition to the verification of the flight software, this simulator can be used for the operational training.

ASTRO-2021-A009

「脚型探査ローバのための振動伝播を用いた牽引力変化に関する実験的研究」

「Experimental investigation of changing traction force caused by a propagation of vibration for planetary exploration rovers with legs」

* 渡邉 智洋(芝浦工業大学・院), 飯塚 浩二郎(芝浦工業大学)

Abstract:

In recent years, the legged rovers are focused on as an exploring rover with high running performance. In this study, changing traction force caused by a propagation of vibration is confirmed. In previous study, walking method which prevents from slip on the loose ground was proposed. The proposed walking method increases traction force by using changes of the ground when giving vibration. In the proposed walking method, increasing traction force by giving the vibration is important. However, changing traction force caused by a propagation of vibration is not studied in detail. In this study, changing traction force by how to give the vibration is confirmed. Moreover, the relationship between vibration time and increasing traction force is confirmed.tory design is developed.

Jul 26th(Mon) Room A PM2(15:45-17:45)　Abstracts

ASTRO-2021-A010

「HAVOK による地球-月三体問題のカオス軌道の解析」

「Data-Driven Analysis of Chaotic Orbits in the Circular Restricted Three Body Problem」

* 浦志 太勢(九大・院), 外本 伸治, 坂東 麻衣(九大)

Abstract:

This paper analyzes chaotic orbits of the Earth-Moon system called ballistic lunar transfer orbit by the data-driven approach called HAVOK. HAVOK analysis decomposes chaotic dynamical system into a linear model with intermittent forcing and has the potential to identify the underlying structure of chaotic dynamical system. The numerical study demonstrates that the chaotic trajectory is reconstructed by the HAVOK model and regions with large intermittent forcing are identified. The relationship between the transport mechanism obtained by HAVOK and the dynamical structure of the circular restricted three-body problem is also revealed by analyzing the periapsis Poincare map.

ASTRO-2021-A011

「MMX ミッションへの応用を目的としたフォボス近接軌道移行解析」

「Phobos proximity orbital transfer analysis with applications to MMX mission」

* プシュパラジ　ニシャント(SOKENDAI/D3), バレージ ニコラ(Lecturer), 川勝 康弘(Professor)

Abstract:

Quasi-satellite orbits are stable retrograde orbits in the restricted three-body problem that have gained attention as a viable candidate for future deep-space missions towards remote planetary satellites. JAXA's robotic sample return mission MMX will utilize QSOs to perform scientific observations of the Martian moon Phobos before landing on its surface and attempt sample retrieval. The complex dynamical environment around Phobos makes the proximity operations of MMX quite challenging and requires novel and sophisticated techniques for maintaining and transferring between different quasi-satellite orbits. The present paper explores the application of bifurcated retrograde orbits to design transfer trajectories around Phobos. The feasibility of using unstable family members as staging orbits between high-altitude and low- ltitude QSOs is later assessed. The final candidates are ranked based on MMX scientific requirements, transfer analyses, and station-keeping costs.

ASTRO-2021-A012

「Ejecta analysis for an asteroid impact event in the perturbed circular restricted three body

problem」

* Trisolini Mirko, Colombo　Camilla(PoliMi), 津田 雄一(ISAS / JAXA)

Abstract:

In a context of future asteroid exploration missions, within the Collecting Asteroid-Orbiting Samples - CRADLE project in collaboration between Politecnico di Milano (Italy) and JAXA, we envision the possibility to perform in-orbit collection. In this work, the dynamical behaviour of ejecta following the impact of a small kinetic impactor is analysed in the context of the circular restricted three body problem. The effect of the impact location is considered, alongside a statistical distribution of the initial ejecta plume. A preliminary mission concept that exploits the passage of particles through the L2 gap is investigated. Specific attention is given to the fate of those ejecta that pass through the L2 gap with conditions that allow their capture. This condition is coupled with the characteristics of the impact and of the ejecta model to study the feasibility of such a solution. A specific application to the case of asteroid Ryugu is presented.

ASTRO-2021-A013

「Trajectory Design Techniques in the CR3BP for a DS-OTV Mission」

* グティエレスラモン ロジャー(SOKENDAI/ISAS), Liang YuyingISAS, 武井 悠人, 佐伯 孝尚, 津田 雄一, 川勝 康弘 ISAS/JAXA

Abstract:

The CR3BP (Circular Restricted Three Body Problem) in its general form is a six dimension problem. In order to design specific trajectories and orbits, intersections between multiple sets of state vectors need to be studied. Although possible, brute-forcing a search of the whole state space of orbits is inefficient and can lead to long computation times. A set of techniques based on parametrization principles as a function of different parameters is presented with the objective of finding intersections between sets of periodic orbit families and natural trajectories derived from them. The results are used as a building block to defining adequate orbits for a DS-OTV (Deep Space Orbit Transfer Vehicle) to be used in future missions, enabling recurring exploration of deep space celestial bodies.

Jul 27th(Mon) Room A AM(9:30-12:00)　Abstracts

ASTRO-2021-A014

「深宇宙への脱出時間を短縮する待機軌道の提案」

「Comet Interception from eArth retrOgrade orbIT viA Lunar gravIty Assist: A Concept Proposal」

* 大島 健太(広工大)
Abstract:
This study explores a stability region and periodic orbits near the 1:1 retrograde resonance with the Moon in the bicircular restricted four-body problem. We find, in addition to lunar distant retrograde orbits and Trojan orbits around the triangular equilibria, another co-orbital stability region in the Earth-Moon system under solar gravitational perturbations. As applications, favorable accessibilities of the Earth's retrograde orbits are demonstrated with ballistic and powered options. Fuel-efficient transfers from the vicinity of the Earth, feasible station-keeping costs, and fast escape trajectories via lunar gravity assists indicate the usefulness of the Earth's retrograde orbits as staging posts for traveling toward the interplanetary region.

ASTRO-2021-A015
「Earth Synchronous Orbit を用いたピギーバック宇宙機のための軌道遷移手法」
「Transfers via Earth Synchronous Orbit for Piggyback Spacecraft」
* 伊藤 大智, プシュパラジ ニシャント（総研大・院）, 川勝 康弘（JAXA）
Abstract:
Geostationary Transfer Orbit (GTO) is a good launching point for deep space missions. Piggyback spacecraft can depart from GTOs at a low cost. However, the primary mission determines GTOs' nature and the launch dates for piggyback missions. This research introduces transferring Earth synchronous orbit (ESO) after departing from GTO, enabling piggyback spacecraft to adjust departure timing from Earth. It also enables the spacecraft to change velocity by introducing Earth swing-by maneuvers. Therefore, ESOs connect GTO and interplanetary trajectory flexibly and reduce the DV required for the transfers. We present the trajectory design process in this talk and show the usefulness quantitatively for GTO to Mars transfer as an example. They provide valuable insights for designing the propulsion system and planning deep space piggyback missions.

ASTRO-2021-A016
「Near Linear Orbit Uncertainty Propagation in Low-Earth Orbit」
* Hernando-Ayuso Javier(ispace), Bombardelli Claudio(UPM), Bau Giulio(UNIPI), Martinez Cacho Alicia(UPM)
Abstract:
A generalized formulation of the equinoctial elements is applied to the orbital uncertainty propagation of an object in Low-Earth orbit. This formulation, recently submitted to CMDA for

journal publication, absorbs the effect of the dominating perturbation term (e.g. J2) in the definition of the orbital elements, introducing the total energy as opposed to the classical Kepler orbital energy.
Additionally, the fast variable is chosen as a time element following the definition of Stiefel and Scheifele thereby making the orbit equations of motion more linear.
In order to test how long the orbit uncertainty propagation preserves its linearity, covariance realism tests are performed comparing the new formulation with classical ones (Cartesian and classical equinoctial). Ballistic and low-thrust maneuvering satellites are considered. The results show that the proposed generalized equinoctial elements preserve linearity for several more revolutions compared to other formulations.

ASTRO-2021-A017
「DDP を利用した軌道設計ソフトウェアの GPU による高速化に関する検討」
「A Study on GPU Acceleration of Trajectory Design Software Using DDP」
* 児玉 俊(ISP), 尾崎 直哉(JAXA), 清水 敏郎, 西岡 拳, 久保 陽平, 染野 和昭, 清水 隆司(ISP), 柳田 幹太, 近澤 拓弥(東大・院)
Abstract:
Space utilization by micro-,nano-satellites has increased in these decades. In addition, after the construction of the lunar gateway in the 2020s, it is expected industry, academia and government enter deep space exploration, such as Mars. At this time, one of the problems of designing the trajectory for low-thrust spacecrafts is the optimum design of multi-revolution trajectory is required considering the many-body problem. In this context, Differential Dynamic Programming (DDP), which derives the optimal control law based on dynamic programming, has attracted much attention because it is capable of stable computation even for large-scale problems. On the other hand, the computation time tends to be long because of the many-body problem, and it becomes even longer when the computational accuracy is increased to accelerate the convergence. We present how to improve the calculation speed and convergence in the trajectory design using DDP by improving the calculation method using GPU.

ASTRO-2021-A018
「軌道部品接続法を用いた土星圏フライバイ往還軌道設計」
「Round Trip Trajectory design by Trajectory Parts Connecting Method」
* 伊藤 大智（総研大・院）, 川勝 康弘（JAXA）
Abstract:

Designing deep space missions involves selecting the most suitable sequence based on mission constraints and requirements to reach the target body. This presentation introduces the “Trajectory Parts Connecting Method,” which treats Keplerian orbits as parts and design sequences by combining them. It enables us to construct possible sequences comprehensively under the given condition at a low computational cost. Moreover, it is the way to verify whether the sequence is the best. We also describe two scenarios for which this method is applicable. The first one is VEGA(Venus Earth Gravity Assist), and another is Saturn flyby round trip. Finally, the study provides new insights on initial guesses for the actual mission design.

Jul 27th(Mon) Room A PM1(13:30-15:30)　Abstracts

ASTRO-2021-A019

「打ち上げ日時の多様性を考慮した DESTINY+スパイラル軌道の多目的設計最適化」

「Multi-objective design optimization of DESTINY+ spiral trajectory in consideration of the diversity of launch date and time」

* 稲塚 遥香（金工大・院），佐々木 大輔（金工大），大山 聖，山本 高行（JAXA）

Abstract:

DESTINY+ is a small-sized high-performance deep space vehicle proposed by ISAS/JAXA. To accomplish the mission, it is necessary to optimize the spiral trajectory of DESTINY+ to minimize the time of flight, to minimize the fuel consumption and to minimize the maximum eclipse period. In this study, multiobjective design optimization of the spiral trajectory was conducted by using multiobjective Evolutionary Algorithms to improve the performance while expanding the launch date and time. The present results and problems will be discussed in the presentation.

ASTRO-2021-A020

「火星衛星の疑周回軌道における軌道設計に関する研究」

「A Study on Design of Quasi-Satellite Orbit around Martian Moon」

* 大木 優介，池田 人(JAXA)，西村 和真，中野 将弥(富士通)

Abstract:

In Martian Moon eXploration (MMX) mission, the spacecraft is operated on Quasi-Satellite Orbit (QSO) around martian moon, Phobos. QSO is stable in circular restricted three body problem (CRTBP). However, considering the relistic dynamics which includes the eccentricty, gravity model, and so on, a part of altitude of QSO becomes unstable. This study presents a method of

maintaing such QSO and designing transfer trajectory between difference QSOs.

ASTRO-2021-A021

「A simple indirect optimization method for J2-perturbed very-low-thrust transfers between circular orbits」

* Barea Adrian, Urrutxua Hodei, Solano-Lopez Pablo(URJC)

Abstract:

This work proposes an indirect optimization method to solve very-low-thrust transfers between circular orbits. Specifically, the considered problem involves continuous tangential and out-of-plane thrust as well as the J2 perturbation. The dynamics is modelled with two averaged equations of motion corresponding to the rates of change of the semimajor axis and the inclination with respect to the target orbit. An optimal control problem to minimize the transfer time is formulated. It is shown that the determination of the suitable initial value of the thrust yaw angle is sufficient to obtain its solution. A one-parameter single shooting method is used to determine it.

ASTRO-2021-A022

「超小型月近傍探査機 EQUULEUS のスイングバイ軌道と観測軌道設計」

「Swingby and Science Orbits Design for the Lunar CubeSat EQUULEUS」

* 近澤 拓弥(東大・院), Dei Tos Diogene Alessandro(JAXA 宇宙研), 川端 洋輔(東大), 柿原 浩太(東大・院), 川勝 康弘(JAXA 宇宙研)

Abstract:

This work presents the trajectory design process of CubeSat mission EQUULEUS, especially the first Lunar swingby and final science orbits. To achieve an optimal transfer trajectory design, we employ B-Plane targeting strategy on first swingby. Our development allows us to capture the global effect of DV1 on trajectories that facilitates quick trajectory design. This presentation also shows the science orbits design for EQUULEUS, which is Earth-Moon halo ortbis, while minimizing eclipse constraint..

Jul 27th(Mon) Room A PM2(15:45-17:45)　Abstracts

ASTRO-2021-A023

「完全燃料フリーの姿勢制御に向けたバイアスモーメンタム方式による片翼展開ソーラーセイル」

「One-Winged One-Wheel Solar Sail: On the Perfect Fuel-Free Attitude Control」

* 高尾 勇輝（JAXA）

Abstract:

For a solar sail, which is under the strong influence of solar radiation pressure (SRP), attitude control is a crucial issue. To produce a specific acceleration, a sailcraft must maintain a required attitude, during which a large amount of angular momentum is accumulated due to the SRP disturbance. In this study, a novel approach for solar sail attitude control is proposed, in which a single-wing solar sail equipped with a single reaction wheel is exploited. This idea makes it possible to naturally keep an attitude of arbitrary sun angle, without the need to cancel disturbances. As a fundamental study, the attitude dynamics under the control are analytically described. The developed framework is validated with some numerical examples.

ASTRO-2021-A024

「衛星の内部エネルギー発散による回転運動の遷移」

「De-tumbling Analysis of Unused Satellite with Flexible Appendages」

* 坂本 諒太郎(コロラド大・院)

Abstract:

The deformations of a tumbling satellite cause internal energy dissipation and spin rate transitions of its spin state. An analysis is demonstrated by the structural approach and rotational dynamics. The interaction between flexible component and de-tumbling is discussed. The motivation of this study is the observation that defunct satellites can be driven into complex rotation states. Although several factors cause spin rate transition, one of that is by the flexible behaviors of satellite component.

ASTRO-2021-A025

「Attitude Control and Probability of Success for JAXA's CubeSat in the 2028 Comet Interceptor Mission」

* Machuca Pablo(Cranfield University), Ozaki Naoya(ISAS), Sanchez Joan Pau, Felicetti Leonard(Cranfield University), Funase Ryu(ISAS)

Abstract:

Comet Interceptor is a collaborative mission between ESA and JAXA that will be launched in 2028. The goal of the mission is to perform the first fly-by of a long-period comet: unknown

target with highly-active dust environment. This work analyzes the attitude performance of JAXA's 24U CubeSat in the mission as it flies through the dust environment. A Monte Carlo analysis is performed to characterize the effect of dust particle impacts on the attitude of the spacecraft, and the likelihood of satisfying narrow-angle camera pointing and angular velocity requirements. Results suggest a probability larger than 90% of satisfying camera requirements despite the extreme, uncertain environment and component inaccuracies. Results also show that a larger reaction wheel implemented along the camera line-of-sight can improve, but only marginally, attitude stability, and evidence the need of properly aligning solar arrays with the incoming flow of particles.

ASTRO-2021-A026

「２Ｕキューブサット"KOSEN-1"における姿勢制御系に関する研究」

「A Study on Attitude Control System for 2U-size Cubesat as KOSEN-1」

* 平社 信人 (群馬高専), 齋藤 創 (群馬高専・機械工学科), 萩原 想大, 伊藤 優介, 鈴木 颯太, 菅原 達弥（群馬高専・専攻科), 今井 雅文（新居浜高専）, 今井 一雅（高知高専）, 野上 正和（信正商事）

Abstract:

In this report, an attitude control system for 2U cubesat "KOSEN-1" as Innovative-2 is conducted then outline of the mission for KOSEN-1 is described. The authors treat the attitude detection system with optimal fusing two omnidirectional cameras and magnetic sensor for 3-axes as COTS. Then the attitude control system for the cubesat is adopted a dual reaction wheel system which each reaction wheel is rotated to opposite direction with a time lag as control variable. Moreover to reduce the equipment space and electric power supply, a novel actuator such as the configuration of the coils deployed horizontally for rotation axis is conducted.

Jul 26th(Mon) Room B AM(9:30-12:00)　Abstracts

ASTRO-2021-B001

「Lyapunov 関数を用いた深層強化学習による宇宙機の適応的姿勢制御」

「Adaptive attitude control of spacecraft via deep reinforcement learning with Lyapunov-based reward design」

* 伊藤 司聖（早大・院）, 柳尾 朋洋（早大）

Abstract:

Recent and future space missions include various purposes, and autonomous spacecraft attitude controllers are getting important. In this study, we numerically implement spacecraft adaptive attitude control including large angle maneuvers via deep reinforcement learning. Deep reinforcement learning is a useful way to address autonomous adaptive attitude control problems. However, it takes vast time to learn the global policy to solve them. We use Lyapunov functions to design rewards for the adaptive attitude control, which improve the learning efficiency and realize more stable learning. Finally, it is shown that the learned policy controls the spacecraft attitude robustly under perturbations of the dynamics.

ASTRO-2021-B002

「磁気トルカによるスピン衛星の姿勢制御実験」

「Attitude Control Experiment of a Spinning Satellite Using Only Magnetic Torquers」

* 木村 洸貴（阪大・研究生），荘司 泰弘（金沢大），佐藤 訓志，山田 克彦（阪大）

Abstract:

A magnetic torquer is an actuator that generates a magnetic moment by passing an electric current to produce torque by interaction with an ambient magnetic field. The control torque is given by the vector product of the magnetic moment and the ambient magnetic field. In comparison to other actuators, such as thrusters and CMGs, the mass and the size of a magnetic torquer are relatively small. Therefore, it is widely used for attitude control of small satellites. However, there is a limitation that a magnetic torquer can only produce torque in the direction perpendicular to the Earth's magnetic field. Also, not so many ground experiments on attitude control by magnetic torquers have been conducted due to the difficulty of reproducing the magnetic field on orbit. This study proposes an attitude control system for spinning satellites using only magnetic torquers and the way of its ground experiments through reproducing the Earth's magnetic field by using Helmholtz coils.

ASTRO-2021-B003

「金沢大学衛星の姿勢制御系の基礎検討」

「Basic study of attitude control system for the Kanazawa Univeristy sattelite 」

* 軸屋 一郎（金大）

Abstract:

The Kanazawa University satellite is a 50 kg-class small satellite whose main purpose is to detect sudden celestial bodies, and is under development with the aim of launching it next year. Due to the demands of astronomical missions and the demands of solar cell charging, it is

planned to be sun-oriented at all times. Attitude control plays an important role because it is equipped with a solar cell paddle deployment mechanism. In this presentation, we will explain the basic study of the attitude control system of the Kanazawa University satellite.

ASTRO-2021-B004

「固体アレイスラスタを用いたモデル予測制御に基づく推力制御に関する研究」

「Research on thrust control based on model predictive control using solid array thrusters」

* 滝瀬 拓実(青学・院), 菅原 佳城, 武田 真和(青学)

Abstract:

The purpose of this study is to propose a thrust control method for attitude control using a solid thruster. A large number of solid thrusters are arranged in an array, and the thrust is controlled by adjusting the number of ignitions and the ignition cycle. In this study, the proposed thrust control by solid array thrusters is performed by combining model predictive control and convolution. The proposed method shows its effectiveness by numerical analysis.

ASTRO-2021-B005

「Destiny+における SAP 独立駆動制御による蓄積外乱除去アルゴリズム」

「Reducing Accumulated Momentum by Indipendent SAP Control for Destiny+ mission 」

* 小澤 祐亮, 中川 弘喜, 保田 誠司, 神谷 俊夫(NEC)

Abstract:

Destiny+ which has been developed in ISAS/JAXA will be operated around the Earth and deep-space to demonstrate spiral raising and interplanetary transfer to Phaethon. In this mission, there are some disturbance torques caused by air drag, solar radiation pressure, and swirl torque of ion engine thrusters. To release the momentum accumulated in the reaction wheel, thruster unloading is operated basically, however, the fuel mass consumed by the operation has critical effect to spacecraft mass budget.

To reduce the fuel consumption, an unloading algorithm that utilize controllability of solar panels is planned to be applied for this mission. The proposed algorithm is to control the angles of two panels independently and change the center of radiation pressure or create swirl torque actively. In this paper, effectiveness of the proposed algorithm is demonstrated by numerical simulation with spacecraft configuration.

Jul 26th(Mon) Room B PM1(13:30-15:30)　Abstracts

ASTRO-2021-B006

「Destiny+での高速フライバイにおけるモデル予測制御に基づく追尾誘導制御則」

「Model Predictive Control (MPC) on Tracking Guidance and Control for High Speed Asteroid Flyby in DESTINY+ Mission」

* 江藤 大輔, 小澤 祐亮, 保田 誠司, 神谷 俊夫(NEC)

Abstract:

In this paper, Model Predictive Control (MPC) for tracking guidance and control by pointing mechanism of mission camera to realize a fine pointing accuracy in DESTINY+ flyby mission is presented and demonstrated. MPC is a discrete-time multi-variable controller. At each control interval, an MPC controller uses an internal model to predict future plant behavior. An observed target direction, i.e. phaethon direction, is calculated from the optical image captured by the mission camera and mirror angle and spacecraft attitude. Once predictive state variables are calculated from state equations, optimal control moves are calculated so as to minimize an evaluation function which is derived from the predictive state variables, weighted functions and a terminal cost function. In order to guarantee the stability, terminal cost function is applied. Comparing to the other classical control theory, advantages of the proposed method is demonstrated by numerical simulation.

ASTRO-2021-B007

「回転駆動望遠鏡によるフライバイ観測のためのミスアライメントを考慮した光学航法・追尾制御」

「Optical Navigation and Tracking Control for Asteroid Flyby Observation with Rotatable Telescope Considering its Miss-Alignment」

* 細沼 貴之(東大), 尾崎 直哉(JAXA), 石橋 高, 洪 鵬(千葉工大), 須崎 祐多(JAXA), 中須賀 真一(東大), 高島 健(JAXA)

Abstract:

In the past few decades, telescopes with rotatable mechanisms have been used for several asteroids flyby observation missions. Although not so much considers has been given to the miss-alignments of the telescopes during the closest flyby phase, the miss-alignments can cause degradation of the navigation/tracking accuracy. This study begins with an evaluation of

the effects of the miss-alignments on navigation/tracking accuracy. And then, a tracking control algorithm combined with UKF-based optical navigation is proposed to mitigate the miss-alignments impact. Finally, the proposed method is evaluated with numerical simulations. The evaluation result shows that the proposed method can improve the navigation/tracking accuracy as well as the convergence speed of the navigation.

ASTRO-2021-B008

「軌道修正時刻と軌道決定時刻の同時最適化」

「Integrated Optimization of Trajectory Correction and Orbit Determination Timing」

* 柿原 浩太（東大・院），尾崎 直哉（JAXA），石川 晃寛（東大），近澤 拓弥（東大・院），船瀬 龍（東大）

Abstract:

In order to reduce the cost of deep space exploration, the number of orbit determination operations could be limited. In this study, we propose a method to achieve mission success by performing trajectory correction maneuvers and orbit determination at the appropriate timing while limiting the number of orbit determination operations. We consider the propagation of probability distributions of the true and estimated states, and use numerical optimization methods to optimize the timing of the trajectory correction maneuvers and orbit determination while satisfying the constraints on the spread of the distributions.

ASTRO-2021-B009

「平衡点周辺における非線形最適制御」

「A Data-Driven Nonlinear Optimal Control of Unstable Fixed Points」

* 佐藤 杏輔（九大・院），外本 伸治，坂東 麻衣(九大)

Abstract:

This paper considers a data-driven optimal control of nonlinear dynamical systems based on the Koopman operator theory. A linear regression model is obtained by the Extended Dynamics Mode Decomposition (EDMD) which is a data-driven algorithm for the approximation of the Koopman operator. A linear quadratic regulator is applied to this dynamics which corresponds to nonlinear optimal control in the state-space. The results of Duffing equation and Hill three body problem demonstrate that the EDMD is able to obtain linear dynamical system and the optimal controlled trajectories exploit the manifold structure of original nonlinear dynamical system.

Jul 26th(Mon) Room B PM2(15:45-17:45)　Abstracts

ASTRO-2021-B010

「火星探査機のスカイクレーン着陸制御における強化学習を用いた制御ゲインチューニング」

「Reinforcement Learning-based Gain Tuning for Sky Crane Landing Control of Mars Exploration Probe」

* 石上 玄也(慶大), 廣田 江太郎(慶大・院)

Abstract:

This paper introduces a gain tuning method for a sky crane landing control for Mars exploration probe. The sky crane considered here equips three active independently driven winch mechanisms with bridles. The winch mechanisms with a classical PID control enable the probe to land on sloped terrain by controlling the length of each bridle. The proposed method in this paper aims to appropriately tune the control gains using reinforcement learning such that the probe posture can be aligned with the slope angle. The simulation study demonstrates the proof of concept of the method.

ASTRO-2021-B011

「進化計算と凸二次計画の複合による誘導軌道の実時間最適化」

「Real-Time Optimization of Guidance Trajectory Using Evolutionary Computation and Convex Quadratic Programming」

* 藤川 貴弘, 米本 浩一（東理大）

Abstract:

A real-time optimal guidance algorithm that generates a variety of flyable trajectories and associated guidance commands is presented. A trajectory expressed as a composite Bezier curve is optimized by an evolutionary algorithm globally and efficiently, with the aid of equality-constrained convex quadratic programming that can make troublesome initial/terminal conditions satisfied. Then, guidance commands for the trajectory tracking are exactly obtained via inverse-dynamics computation. Validity of the proposed method is demonstrated through its application to the return guidance simulation of a suborbital spaceplane.

ASTRO-2021-B012

「サブオービタルスペースプレーンの多目的複合領域設計最適化」
「Multi-Objective, Multidisciplinary Design Optimization of Suborbital Spaceplane」
* 藤川 貴弘, 米本 浩一（東理大）
Abstract:
The conceptual design of suborbital spaceplane is investigated considering two mission configurations (i.e., orbital and suborbital transportation). While it is expected that such a multi-purpose vehicle concept can save the total development cost, its transportation performance may be inferior to that of single-purpose vehicles specialized for specific missions. Considering this issue, multidisciplinary design optimization with two objectives for maximizing orbital and suborbital transportation performances is conducted. In order to optimize the vehicle design and two mission trajectories in an integrated and efficient way, a decomposition-based multi-objective evolutionary algorithm and a gradient-based optimization method are applied to vehicle design and trajectory design, respectively, with a nested structure.

ASTRO-2021-B013
「モーションプランニングを用いた宇宙機の近接運用誘導」
「Guidance for Spacecraft Proximity Operation Using Motion Planning Techniques」
* 石塚 智大(ISAE-SUPAERO・院)
Abstract:
Real-time guidance for spacecraft proximity operations is essential for rendezvous and docking maneuvers, space debris inspections and asteroid landing missions. Propellant optimality is one of the most important constraints for the autonomous guidance system and this constraint makes the retrieval of numerically efficient and effective guidance laws more challenging.
This study develops the numerically efficient and propellant-optimized spacecraft autonomous guidance strategy for proximity operations. A sampling-based motion planning technique, Fast marching Tree (FMT*), is proposed as the computational core to generate trajectories in real time. Three different dynamics models are considered: Clohessy-Wiltshire-Hill model, Schweighart-Sedwick model and Circular Restricted Three-Body Problem (CR3BP). The FMT* performances under each dynamics model are evaluated and the feasibility of the real-time guidance for spacecraft proximity operations is discussed.

Jul 26th(Mon) Room B AM(9:30-12:00)　Abstracts

ASTRO-2021-B001

「Lyapunov 関数を用いた深層強化学習による宇宙機の適応的姿勢制御」

「Adaptive attitude control of spacecraft via deep reinforcement learning with Lyapunov-based reward design」

* 伊藤 司聖（早大・院），柳尾 朋洋（早大）

Abstract:

Recent and future space missions include various purposes, and autonomous spacecraft attitude controllers are getting important. In this study, we numerically implement spacecraft adaptive attitude control including large angle maneuvers via deep reinforcement learning. Deep reinforcement learning is a useful way to address autonomous adaptive attitude control problems. However, it takes vast time to learn the global policy to solve them. We use Lyapunov functions to design rewards for the adaptive attitude control, which improve the learning efficiency and realize more stable learning. Finally, it is shown that the learned policy controls the spacecraft attitude robustly under perturbations of the dynamics.

ASTRO-2021-B002

「磁気トルカによるスピン衛星の姿勢制御実験」

「Attitude Control Experiment of a Spinning Satellite Using Only Magnetic Torquers」

* 木村 洸貴（阪大・研究生），荘司 泰弘（金沢大），佐藤 訓志，山田 克彦（阪大）

Abstract:

A magnetic torquer is an actuator that generates a magnetic moment by passing an electric current to produce torque by interaction with an ambient magnetic field. The control torque is given by the vector product of the magnetic moment and the ambient magnetic field. In comparison to other actuators, such as thrusters and CMGs, the mass and the size of a magnetic torquer are relatively small. Therefore, it is widely used for attitude control of small satellites. However, there is a limitation that a magnetic torquer can only produce torque in the direction perpendicular to the Earth's magnetic field. Also, not so many ground experiments on attitude control by magnetic torquers have been conducted due to the difficulty of reproducing the magnetic field on orbit. This study proposes an attitude control system for spinning satellites using only magnetic torquers and the way of its ground experiments through reproducing the

Earth's magnetic field by using Helmholtz coils.

ASTRO-2021-B003

「金沢大学衛星の姿勢制御系の基礎検討」

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* 軸屋 一郎（金大）

Abstract:

The Kanazawa University satellite is a 50 kg-class small satellite whose main purpose is to detect sudden celestial bodies, and is under development with the aim of launching it next year. Due to the demands of astronomical missions and the demands of solar cell charging, it is planned to be sun-oriented at all times. Attitude control plays an important role because it is equipped with a solar cell paddle deployment mechanism. In this presentation, we will explain the basic study of the attitude control system of the Kanazawa University satellite.

ASTRO-2021-B004

「固体アレイスラスタを用いたモデル予測制御に基づく推力制御に関する研究」

「Research on thrust control based on model predictive control using solid array thrusters」

* 滝瀬 拓実(青学・院), 菅原 佳城, 武田 真和(青学)

Abstract:

The purpose of this study is to propose a thrust control method for attitude control using a solid thruster. A large number of solid thrusters are arranged in an array, and the thrust is controlled by adjusting the number of ignitions and the ignition cycle. In this study, the proposed thrust control by solid array thrusters is performed by combining model predictive control and convolution. The proposed method shows its effectiveness by numerical analysis.

ASTRO-2021-B005

「Destiny+における SAP 独立駆動制御による蓄積外乱除去アルゴリズム」

「Reducing Accumulated Momentum by Indipendent SAP Control for Destiny+ mission 」

* 小澤 祐亮, 中川 弘喜, 保田 誠司, 神谷 俊夫(NEC)

Abstract:

Destiny+ which has been developed in ISAS/JAXA will be operated around the Earth and deep-space to demonstrate spiral raising and interplanetary transfer to Phaethon. In this mission, there are some disturbance torques caused by air drag, solar radiation pressure, and swirl torque

of ion engine thrusters. To release the momentum accumulated in the reaction wheel, thruster unloading is operated basically, however, the fuel mass consumed by the operation has critical effect to spacecraft mass budget.
To reduce the fuel consumption, an unloading algorithm that utilize controllability of solar panels is planned to be applied for this mission. The proposed algorithm is to control the angles of two panels independently and change the center of radiation pressure or create swirl torque actively. In this paper, effectiveness of the proposed algorithm is demonstrated by numerical simulation with spacecraft configuration.

Jul 26th(Mon) Room B PM1(13:30-15:30)　Abstracts

ASTRO-2021-B006
「Destiny+での高速フライバイにおけるモデル予測制御に基づく追尾誘導制御則」
「Model Predictive Control (MPC) on Tracking Guidance and Control for High Speed Asteroid Flyby in DESTINY+ Mission」
* 江藤 大輔, 小澤 祐亮, 保田 誠司, 神谷 俊夫(NEC)
Abstract:
In this paper, Model Predictive Control (MPC) for tracking guidance and control by pointing mechanism of mission camera to realize a fine pointing accuracy in DESTINY+ flyby mission is presented and demonstrated. MPC is a discrete-time multi-variable controller. At each control interval, an MPC controller uses an internal model to predict future plant behavior. An observed target direction, i.e. phaethon direction, is calculated from the optical image captured by the mission camera and mirror angle and spacecraft attitude. Once predictive state variables are calculated from state equations, optimal control moves are calculated so as to minimize an evaluation function which is derived from the predictive state variables, weighted functions and a terminal cost function. In order to guarantee the stability, terminal cost function is applied. Comparing to the other classical control theory, advantages of the proposed method is demonstrated by numerical simulation.

ASTRO-2021-B007
「回転駆動望遠鏡によるフライバイ観測のためのミスアライメントを考慮した光学航法・追尾制御」
「Optical Navigation and Tracking Control for Asteroid Flyby Observation with Rotatable

Telescope Considering its Miss-Alignment」

* 細沼 貴之(東大), 尾崎 直哉(JAXA), 石橋 高, 洪 鵬(千葉工大), 須崎 祐多(JAXA), 中須賀 真一(東大), 高島 健(JAXA)

Abstract:

In the past few decades, telescopes with rotatable mechanisms have been used for several asteroids flyby observation missions. Although not so much considers has been given to the miss-alignments of the telescopes during the closest flyby phase, the miss-alignments can cause degradation of the navigation/tracking accuracy. This study begins with an evaluation of the effects of the miss-alignments on navigation/tracking accuracy. And then, a tracking control algorithm combined with UKF-based optical navigation is proposed to mitigate the miss-alignments impact. Finally, the proposed method is evaluated with numerical simulations. The evaluation result shows that the proposed method can improve the navigation/tracking accuracy as well as the convergence speed of the navigation.

ASTRO-2021-B008

「軌道修正時刻と軌道決定時刻の同時最適化」

「Integrated Optimization of Trajectory Correction and Orbit Determination Timing」

* 柿原 浩太（東大・院）, 尾崎 直哉（JAXA）, 石川 晃寛（東大）, 近澤 拓弥（東大・院）, 船瀬 龍（東大）

Abstract:

In order to reduce the cost of deep space exploration, the number of orbit determination operations could be limited. In this study, we propose a method to achieve mission success by performing trajectory correction maneuvers and orbit determination at the appropriate timing while limiting the number of orbit determination operations. We consider the propagation of probability distributions of the true and estimated states, and use numerical optimization methods to optimize the timing of the trajectory correction maneuvers and orbit determination while satisfying the constraints on the spread of the distributions.

ASTRO-2021-B009

「平衡点周辺における非線形最適制御」

「A Data-Driven Nonlinear Optimal Control of Unstable Fixed Points」

* 佐藤 杏輔（九大・院）, 外本 伸治, 坂東 麻衣(九大)

Abstract:

This paper considers a data-driven optimal control of nonlinear dynamical systems based on

the Koopman operator theory. A linear regression model is obtained by the Extended Dynamics Mode Decomposition (EDMD) which is a data-driven algorithm for the approximation of the Koopman operator. A linear quadratic regulator is applied to this dynamics which corresponds to nonlinear optimal control in the state-space. The results of Duffing equation and Hill three body problem demonstrate that the EDMD is able to obtain linear dynamical system and the optimal controlled trajectories exploit the manifold structure of original nonlinear dynamical system.

Jul 26th(Mon) Room B PM2(15:45-17:45)　Abstracts

ASTRO-2021-B010

「火星探査機のスカイクレーン着陸制御における強化学習を用いた制御ゲインチューニング」

「Reinforcement Learning-based Gain Tuning for Sky Crane Landing Control of Mars Exploration Probe」

* 石上 玄也(慶大), 廣田 江太郎(慶大・院)

Abstract:

This paper introduces a gain tuning method for a sky crane landing control for Mars exploration probe. The sky crane considered here equips three active independently driven winch mechanisms with bridles. The winch mechanisms with a classical PID control enable the probe to land on sloped terrain by controlling the length of each bridle. The proposed method in this paper aims to appropriately tune the control gains using reinforcement learning such that the probe posture can be aligned with the slope angle. The simulation study demonstrates the proof of concept of the method.

ASTRO-2021-B011

「進化計算と凸二次計画の複合による誘導軌道の実時間最適化」

「Real-Time Optimization of Guidance Trajectory Using Evolutionary Computation and Convex Quadratic Programming」

* 藤川 貴弘, 米本 浩一（東理大）

Abstract:

A real-time optimal guidance algorithm that generates a variety of flyable trajectories and associated guidance commands is presented. A trajectory expressed as a composite Bezier

curve is optimized by an evolutionary algorithm globally and efficiently, with the aid of equality-constrained convex quadratic programming that can make troublesome initial/terminal conditions satisfied. Then, guidance commands for the trajectory tracking are exactly obtained via inverse-dynamics computation. Validity of the proposed method is demonstrated through its application to the return guidance simulation of a suborbital spaceplane.

ASTRO-2021-B012

「サブオービタルスペースプレーンの多目的複合領域設計最適化」

「Multi-Objective, Multidisciplinary Design Optimization of Suborbital Spaceplane」

* 藤川 貴弘, 米本 浩一（東理大）

Abstract:

The conceptual design of suborbital spaceplane is investigated considering two mission configurations (i.e., orbital and suborbital transportation). While it is expected that such a multi-purpose vehicle concept can save the total development cost, its transportation performance may be inferior to that of single-purpose vehicles specialized for specific missions. Considering this issue, multidisciplinary design optimization with two objectives for maximizing orbital and suborbital transportation performances is conducted. In order to optimize the vehicle design and two mission trajectories in an integrated and efficient way, a decomposition-based multi-objective evolutionary algorithm and a gradient-based optimization method are applied to vehicle design and trajectory design, respectively, with a nested structure.

ASTRO-2021-B013

「モーションプランニングを用いた宇宙機の近接運用誘導」

「Guidance for Spacecraft Proximity Operation Using Motion Planning Techniques」

* 石塚 智大(ISAE-SUPAERO・院)

Abstract:

Real-time guidance for spacecraft proximity operations is essential for rendezvous and docking maneuvers, space debris inspections and asteroid landing missions. Propellant optimality is one of the most important constraints for the autonomous guidance system and this constraint makes the retrieval of numerically efficient and effective guidance laws more challenging.

This study develops the numerically efficient and propellant-optimized spacecraft autonomous guidance strategy for proximity operations. A sampling-based motion planning technique, Fast marching Tree (FMT*), is proposed as the computational core to generate trajectories in real time. Three different dynamics models are considered: Clohessy-Wiltshire-Hill model,

Schweighart-Sedwick model and Circular Restricted Three-Body Problem (CR3BP). The FMT* performances under each dynamics model are evaluated and the feasibility of the real-time guidance for spacecraft proximity operations is discussed.

Jul 26th(Mon) Room C PM1(13:30-15:30) Abstracts

ASTRO-2021-C006

「フォーメーション維持における推薬残量差を考慮した推薬バランシング」

「Propellant Balancing Considering the Propellant Remaining Difference in Formation Maintenance」

* 神林 賢(東大・院), 伊藤 琢博, 坂井 真一郎(JAXA)

Abstract:

Formation maintenance is the process of controlling multiple satellites to keep them in the desired shape. Because of the nature of handling multiple satellites, propellant balancing which equalizes the propellant consumption is important for the mission duration. However, maintenance maneuvers that do not consider the remaining propellant amount difference may affect the mission duration. This paper presents the method of propellant balancing according to the remaining propellant amount difference. In this method, The virtual chief satellite in GCO will be placed in the optimal position to extend the mission duration.

ASTRO-2021-C007

「EOL 軌道離脱サービスのための、電気推進とレーザーアブレーションを用いた低推力編隊飛行」

「Low-Thrust Formation Flight Using Electric Propulsion and Laser Ablation for End-of-Life Deorbit Service」

* 白澤 洋次, 岩田 隆敬(JAXA)

Abstract:

In order to reduce a generation of space debris, an End-of-Life service has been proposed that uses laser ablation thrust to provide a deorbiting force to a non-operational target satellite. To generate the ablation on the target satellite's surface, a service satellite equipped with a laser for irradiation will approach the target within a focal range of the laser. In addition, for continuous laser ablation, the service satellite maintains its relative position in accordance with the change of the target satellite's orbit caused by the ablation force. These orbit control of the service

satellite is planned to be performed by electric propulsion for efficiency, and due to power constraints, the orbit control and the laser ablation will be performed exclusively. In this paper, a method to perform a formation flying using electric propulsion and ablation force under these constraints, and a result of simulation of the method is presented.

ASTRO-2021-C008

「太陽-地球系 L2 点近傍におけるフォーメーションフライトでの太陽輻射圧を利用した相対位置制御と小円ハロー軌道の維持について」

「Simultaneous Station and Formation Keeping using Solar Radiation Pressure in Artificial Halo Orbits about the SEL2 Point」

* 杉浦 圭佑（青学・院），杉原 アフマッド 清志，高尾 勇輝（JAXA），菅原 佳城（青学），森 治（JAXA）

Abstract:

In optical astronomy, physically achievable spatial resolution is limited by the physical telescope size, i.e. the diffraction limit. However, launching very large telescopes into space is impractical, therefore, interferometric observations using satellite formation flight are often proposed. In order to obtain an image with an interferometer, it is necessary to change the distance and relative orientation between the telescopes during the observation. In conventional formation flight interferometers, fuel is consumed in this process.

In this work, the authors propose to place a formation flight interferometer on an artificial halo orbit around the Sun-Earth L2 orbit, in which the solar radiation pressure is used as the only control input. With this suggestion, it is expected to realize the maintenance control of the artificial halo orbit and relative position control without consuming fuel.

ASTRO-2021-C009

「超超小型衛星での相対軌道姿勢連成系における編隊配置の安定性解析」

「Stability Analysis of Formation Configuration in Relative Orbit Attitude Coupled Pico-Satellite Formation Flying 」

* 野呂 拓臣（名大・院），稲守 孝哉, Park Ji Hyun（名大）

Abstract:

Pico-satellites formation flying could be useful for distributed space systems. Utilizing the numerous number of satellites, they enable the establishment of space Interferometer, high gain adaptive antenna, and MIMO communication systems.

Formation configuration has a significant role to establish a pico-satellites swarm system.

Conventional studies considered the configuration under orbit disturbances. However, as satellites become small, the magnetic effect due to the scale effect becomes stronger, and the relative orbit and attitude of pico-satellites with magnetic torque are coupled via magnetic force and torque, and plasma drag. This research considers the formation configuration coupled with relative orbit and attitude and periodic stability analysis is conducted.

Jul 26th(Mon) Room C PM2(15:45-17:45)　Abstracts

ASTRO-2021-C010

「高精度な距離管理が不要な分散宇宙機群電波干渉観測システム構築に向けた SDR による信号処理実験」

「SDR Signal Processing Experiments for Distributed Spacecraft Radio Interferometry System without Precise Distance Management」

* 名田 悠一郎, 藤田 雅弘(東大・院), 高尾 勇輝, 杉原 アフマッド清志(JAXA), 川口 淳一郎(東北大)

Abstract:

This study presents a novel communication methodology for distributed spacecraft radio interferometer systems without precise distance management. We introduce duplication of signal propagation line and phase cancellation by mixing processing on a parent spacecraft. Another reference signal from a distant radio source plays a role in duplicating the signal propagation line. Each spacecraft relays both signals individually and a parent spacecraft, then that parent accumulates all signals and conducts the phase cancellation individually. This methodology removes the uncertainties of phase fluctuations that differ from one child to another. We conduct signal processing experiments both only on PC and with SDRs to verify the methodology. This research contributes to improving the feasibility and availability of communication and observation systems utilizing multiple spacecrafts.

ASTRO-2021-C011

「コンステレーション衛星における軌道位相調整とメンテナンスの実運用について」

「Practical Satellite Constellation Operation for Orbit Phasing and Maintenance」

* 大熊 成裕, チュウ ビー クワン, 清水 健介, 三川 祥典, ジメノ アルフォンソ アルボナ, アナンド アミット, 倉田 稔, 國母 隆一(Axelspace)

Abstract:

The proliferation of low earth orbit small satellites for various application, these satellites often work as a constellation to provide network effect advantages and commercial values. Constellation operation has become an essential capability to ensure the satellites could coordinate, phase and maintain their orbit. This paper aims at addressing challenges of constellation formation between existing and newly inserted satellites and how the orbit is maintained throughout the mission using the practical case of the GRUS-1 satellites forming the Axelglobe constellation for earth observation application.

ASTRO-2021-C012

「直線に並ぶ宇宙干渉計のための燃料最適な観測軌道の設計」

「Fuel-Optimal Path Planning for an Earth-orbiting linear space interferometer」

* 近藤 宙貴（東大・院），五十里 哲（東大），松尾 太郎（名大）

Abstract:

Space interferometry by Earth-orbiting spacecraft has been considered as an important step to realize large-scale interferometric missions in the future. Because more perturbations on relative orbits exist in Earth orbits, formation control strategy needs to account for more complicated orbital dynamics rathar than a simple model assumed by existing methods. In order to assure stable observation by an interferometer, periodic relative orbits are used for both continuous and point coverage of uv-plane. For point coverage of uv-plane, numerical optimization is introduced, and then the proposed method is validated numerical simulation.

ASTRO-2021-C013

「宇宙機の精密位置制御が不要な宇宙機群電波干渉計の電波強度分布推定手法の提案」

「Proposal of estimation method of radio intensity distribution for a multi-spacecraft radio interferometer that do not require precise position control of spacecraft」

* 藤田 雅大, 名田 悠一郎(東大・院), 川口 淳一郎(東北大)

Abstract:

A radio interferometer implemented by a group of spacecraft has not been achieved yet because it is difficult to precisely measure the relative positions of the spacecraft. We propose a new communication method to solve those problems. This method makes it possible to accumulate the observation information without accurate measurement of the distances. We also establish an estimation method of the signal intensity distribution of the observation object from the observation information. In this method, the distribution is estimated by correcting a linear solution derived from the relationships between the observation information and the signal

intensity distribution. Simulations are performed to verify those methods and indicates that it is possible to estimate the position of the signal source even if the error is included in the information on the spacecraft positions. The effectiveness of the proposed methods is shown by the simulations.

Jul 26th(Mon) Room C AM(9:30-12:00)　Abstracts

ASTRO-2021-C001

「非協力的なターゲットの動きを推定する手法 - 評価パッケージ」

「Motion Estimator for Uncooperative Target ? An Assessment Package」

* モンテイロ パドバン チアゴ(Patchedconics), 楠本 哲也（東大・学）, 川口 淳一郎(Patchedconics)

Abstract:

Patchedconics has developed a robust Motion Estimator capable of identifying information about a target by observing markers placed on its surface. Even the angular momentum direction is solved by the Motion Estimator, an issue that has been studied for decades, and mostly approached using linearized filters, which require reference models. We present the Assessment Package which allow users to test the functionality of the Motion Estimator. The package includes the executable file for the Motion Estimator and Simulators codes. The user can use the provided Simulators for testing or design their own, using the one included in the package as a reference.

ASTRO-2021-C002

「HTV-X 自動ドッキング技術実証ミッションに係る近傍運用と航法誘導制御系設計」

「Proximity Operation and Guidance Navigation and Control Design for HTV-X Automated Docking Demonstration Mission」

* 佐々木 貴広, 冨田 悠貴, 近藤 義典, 蜂谷 友理, 日高 萌子, 武井 悠人, 中村 涼, 山元 透(JAXA)

Abstract:

Japan Aerospace Exploration Agency (JAXA) is developing the next generation unmanned rendezvous visiting vehicle "HTV-X" to provide not only the advanced cargo transportation capability for the International Space Station but also the service as the technology tryout platform in low Earth orbit at the end of its mission. JAXA plans to demonstrate the proximity

operation and automated docking technique with this plat foam. This paper presents the concept of a GNC strategy to address 6 degrees-of-freedom spacecraft attitude and position control for future HTV-X docking missions.

ASTRO-2021-C003

「HTV-X 自動ドッキングのための ISS 回り込みストラテジの検討」

「ISS Fly Around Strategy for Automated Docking on HTV-X」

* 日高 萌子, 村上 尚美, 佐々木 貴広, 冨田 悠貴, 蜂谷 友理, 近藤 義典, 内山 崇, 前田 真紀, 中村 涼, 山元 透, 山中 浩二(JAXA)

Abstract:

Japan Aerospace Exploration Agency (JAXA) plans to demonstrate the automated docking technique with the next generation visiting vehicle "HTV-X" for the future cis-lunar Gateway mission where the crew-based operation is not available.

The docking demonstration will start after the HTV-X departs from the ISS. The HTV-X will then fly around to the zenith side of the ISS using the Lidar navigation and approach the ISS parallel to the R-bar for docking.

This paper presents a GNC strategy including the Lidar navigation algorithm for the fly -around phase. The safety of the proposed scenarios is demonstrated through numerical simulations.

ASTRO-2021-C004

「制限された三体問題における自律ランデブーとドッキングのためのダイナミクス、ガイダンスと制御」

「Dynamics, Guidance and Control for Autonomous Rendezvous and Docking in the Restricted Three-Body Problem」

* Cuevas del Valle Sergio, Urrutxua Cereijo Hodei, Solano Lopez Pablo(URJC)

Abstract:

Deep space missions have gained increasing interest from the Space Industry in recent times, their maximum exponent being the establishment of a lunar gateway within this decade. To that end, multi-body dynamics and autonomous rendezvous and docking have been defined as crucial technologies and concepts to expand and maintain human space activities beyond near Earth orbit.

In this work, a Hamiltonian derivation of the Restricted Three-Body Problem relative dynamics is presented, exploring the phase space topology, particular solutions and analogies to perturbed Keplerian motion. In addition,　based on these results, a family of optimal linear and nonlinear

Guidance and Control techniques are developed and validated to exploit this multi-body context and its intrinsic structures for rendezvous and proximity operations missions.

ASTRO-2021-C005

「深宇宙 OTV 構想の検討状況」

「Deep Space Orbital Transfer Vehicle (DS-OTV): the status of conceptual studies」

* 武井 悠人, 佐伯 孝尚, 丸 祐介, 尾川 順子, 三桝 裕也(JAXA), Gutierrez Ramon Roger , 山川 真以子(SOKENDAI), 津田 雄一(JAXA)

Abstract:

The concept of Deep Space Orbital Transfer Vehicle (DS-OTV) was inspired by the Hayabusa2's precise landings with sub-meter accuracy in deep space. The OTV usually stays in the periodic orbit with the energy level of C3≒0 and possesses autonomous rendezvous-docking (RVD) capability in deep space. As the client probe being launched, the OTV performs RVD and provides services such as refueling and orbit transfer to the probe.

This presentation reports current progresses of concept studies: the possible stand-by periodic orbits explored in CR3BP, the autonomous proximity rendezvous capability inheriting the Hayabusa2 technology, and the docking and refueling mechanism suitable for the DS-OTV concept.d.

Jul 27th(Mon) Room C AM(9:30-12:00)　Abstracts

ASTRO-2021-C014

「Novel Robotic Solutions for Space Exploration and Colonization」

* Bonardi Stephane, 二階堂 利久, 久保田 孝(JAXA)

Abstract:

In this talk, we present innovative and disruptive robotics' concepts to tackle the challenges of space exploration, with the long-term goal of creating permanent human colonies in extraterrestrial environments. We introduce the notion of robotic exoskeletons and soft modular robots, then show how they can be combined with advanced Artificial Intelligence and Deep Learning techniques to create a versatile and efficient robotics framework for space exploration and colonization. We also describe additional application scenarios for our approach, including situations that apply to Earth right now, such as disaster relief and hazardous environment analyses.

ASTRO-2021-C015

「トランスフォーマーミッションへの強化学習」

「Reinforcement Learning for Transformer Mission」

* ベルトラン ロジャー(東大・院), 津田 雄一, 川口 淳一郎(JAXA), 久保 勇貴(東大)

Abstract:

In this research, a transformable spacecraft for the JAXA's Transformer Mission is studied. One of the major features of the spacecraft is that it can change its shape by means of inner force actuators so as to perform different in-space operations, such as telescope mode or station keeping. This property can be actually exploited in order to perform attitude change without the need of external force devices . Furthermore, by choosing an appropriate path, both body configuration and attitude can be changed at the same time in what is known as a reorienting transformation, what is not possible with other inner force devices such as rotation wheels. Nonetheless, this problem has a strong nonlinearity, high-dimensionality and underactuation, which make a Control Theory approach specially challenging. In this work, instead, a novel path planning algorithm is designed by applying the principles of Reinforcement Learning to the problem.

ASTRO-2021-C016

「トランスフォーマーロボットの直線的ボディ再構成における姿勢運動の解析解」

「Analytical Attitude Solution for Rectilinear Body Reconfiguration of Transformer Robot」

* 久保 勇貴(東大・院), 川口 淳一郎(東北大)

Abstract:

Reconfigurable free-flying space robots (Transformer robots) are expected to be able to adapt to various mission environments by changing their functions dynamically and flexibly. Due to the non-holonomic nature of the angular momentum conservation law, the final attitude after the reconfiguration depends on its reconfiguration path, where the path design is a very difficult problem. In this study, we originally derive an analytical solution for a rectilinear reconfiguration path. This analytical solution is a powerful tool to systematically design the reconfiguration path which achieves desired attitude and body configuration simultaneously.

ASTRO-2021-C017

「構造変形可能な宇宙機の駆動部摩擦による相互干渉を考慮した相対角度制御に関する研

究 」

「Relative angle control considering mutual interference due to friction of the drive unit of a spacecraft whose structure is deformable」

* 池田 宏太朗(青学・院), 森 治(JAXA), 菅原 佳城(青学)

Abstract:

A group centered on JAXA is developing a transformer spacecraft consisting of multiple panels and drive hinges. This spacecraft can be transformed into various shapes by moving the hinges, and can perform multiple missions. However, motion analysis becomes difficult due to mutual interference such as friction caused by multiple elements during deformation. Therefore, in this research, I perform a simulation by introducing a non-smooth friction model that makes it easy to express mutual friction of friction. In addition, I plan to confirm the validity of the model by conducting verification experiments.

ASTRO-2021-C018

「非ホロノミック性を利用した可変構造宇宙機の 3 次元姿勢変化」

「Three-dimensional Attitude Change of Variable-structured Spacecraft by Utilizing Non-holonomic Features」

* 竹内 咲希, 池田 幹太(九大・院), 坂東 麻衣, 外本 伸治(九大)

Abstract:

Variable-structured Spacecraft can change its attitude through transformation of its overall configuration by utilizing the non-holonomic features for the angular momentum conservation. In previous works, rotational motion in two-dimension was widely studied, and some researchers deals with three-dimensional motion by fewer number of control inputs. This paper discusses the attitude motion in three-dimension of transformable structures connected by revolutional joints under no external forces/torques.

Jul 27th(Mon) Room C PM1(13:30-15:30)　Abstracts

ASTRO-2021-C019

「無重力－重力環境下にある液体タンクのスロッシングモデル」

「Sloshing Models of Liquid Tanks in the Zero- to Micro-gravity Environments」

* 藤田 和央, 馬場 満久, 大槻 真嗣(JAXA)

Abstract:

To describe the behavior of a liquid tank, it is common to use different sloshing models for different environments, such as a sloshing model derived from surface tension in a zero-gravity environment and a transverse sloshing model perpendicular to gravity in a gravity environment. However, when landing from zero gravity to a gravitational body, as in the case of MMX, a sloshing model applicable to both is required. In this study, as a potential example, we propose a relatively simple model that is applicable to MMX.

ASTRO-2021-C020

「高密度に折り畳まれたデバイス付き宇宙膜構造の展開シミュレーション」

「Deployment Simulation of a Tightly-Folded Device-Laden Space Membrane Structure」

* 山田 修平（東大・院），森 治，杉原 清志（JAXA）

Abstract:

Light-weight and compactly foldable membranes can be an advantageous alternative to existing spacecraft structural materials. However, since membrane dynamics under micro-g vacuum environment is difficult to replicate during ground test, much insights are needed on space membrane behavior, especially its deployment dynamics. In this study, a membrane spacecraft component (HELIOS), scheduled to launch in 2022, is modeled and simulated as a mass-spring system. In such tightly-folded device-laden membranes, understanding the mechanisms for membrane entanglement during deployment is of central importance. To gain new understanding in this field and to inform the design of such membrane space structures, entanglement phenomena and the resulting extra motor loads are explored by modeling membrane-membrane interaction (contact mechanics). Using this dynamical model, deployments under different configurations are simulated.

ASTRO-2021-C021

「二次元自己展開パネル構造に用いる結合フィルムが展開に及ぼす影響」

「Effects of Elastic Film Hinges on Deployment for Two-Dimensional Self-Deployable Panel Structures」

* 中嶋 哲大(東工大・学)，古谷 寛(東工大)

Abstract:

宇宙展開構造の構築において，二次元展開パネル構造の研究がなされている．著者らは，曲率を持つパネルをフィルムヒンジで繋ぎ，収納時に蓄えたひずみエネルギーの開放によって展開する二次元自己展開パネル構造を提案してきた．この提案するパネル構造は，パネルを結合するフィルムヒンジ部の変形と弾性パネルの変形による弾性エネルギーがパネルの

展開特性に影響すると考えられる．本研究は，二次元パネル構造に用いる結合フィルムが自己展開に及ぼす影響を実験的に検討する．実験では，パネル間隔を変更することで結合フィルム部のすき間を変えた「矩形折り」および「ミウラ折り」による平板パネルのモデルを試作し，折り畳んだモデルが自由落下および重力補償下で自己展開した際の展開長さを計測することで展開特性を評価した．以上の実験より，結合ヒンジ部のすき間が二次元パネル構造の展開後形状に与える影響を定量的に明らかにした．

ASTRO-2021-C022

「ANCF2 次元柔軟梁における折り目剛性を考慮した展開挙動解析」

「Deployment Analysis of an ANCF Plannar Beam Considering Crease Stiffness」

* 鈴木 賢(青学・院), 菅原 佳城(青学), 森 治(JAXA)

Abstract:

This research studies deployment analysis methods of the flexible structure which is adaptable to analysis of the solar sail. In the former solar sail project “IKAROS” conducted by JAXA, asymmetric deployment of the sail was confirmed. One of the cause of this phenomenon is considered to be crease stiffness on the flexible structure. In this study, absolute nodal coordinate formulation (ANCF), which is a type of nonlinear finite element method, is used since it has an advantage that it can well describe the motion of the flexible multibody system with large deformation and large rotation. The purposes of this study are to express creases on a planar beam element on the flexible plate structure by ANCF and to evaluate the analysis result in comparison with the result by Multi-Particle Method, which is the major method in analyzing deployment of the solar sail.

Jul 27th(Mon) Room C PM2(15:45-17:45)　Abstracts

ASTRO-2021-C023

「識別可能な複数の人工マーカーを用いた小惑星の着陸のための最適配置」

「Optimal Positions of Multiple Identifiable Artificial Landmarks for a Touchdown on an Asteroid」

* 楠本 哲也(東大・院), 森 治(JAXA)

Abstract:

A spherical landmark called target marker has been utilized for the guidance and navigation of touchdowns in asteroid missions. Although utilizing multiple markers will contribute to higher accuracy, using conventional target markers for that purpose is not suitable for navigation

because they are not identifiable. Therefore, we propose a new target marker that is a membrane with a pattern on its surface, making it to be identifiable. In this study, we investigate the optimal position of the target markers on the asteroid surface for conducting accurate navigation.

ASTRO-2021-C024

「DESTINY+搭載小惑星追尾望遠カメラの駆動鏡検討」

「Initial development of asteroid tracking mirror for telescopic camera onboard DESTINY+ spacecraft」

* 洪 鵬, 石橋 高(千葉工大), 須崎 祐多(JAXA), 山田 学(千葉工大), 細沼 貴之(東大), 尾崎 直哉, 宮原 剛, 太田 方之, 佐藤 峻介, 大槻 真嗣, 豊田 裕之, 西山 和孝(JAXA), 奥平 修(千葉工大), 高島 健(JAXA)

Abstract:

The telescopic camera onboard DESTINY+ spacecraft is planned to perform high-resolution imaging during the high-speed flyby of asteroid 3200 Phaethon with an imaging rate of more than 1 frame per second and with a spatial resolution down to 3.5 m/px at closest approach. Since the relative flyby speed and closest distance to Phaethon are expected to be 30 to 36 km/s and about 500 km (i.e., an angular velocity of ≧4 deg/s at maximum), it is significantly difficult to track the asteroid only by the rotation of the spacecraft itself. Therefore, an asteroid tracking mirror, which can rotate at an angular velocity higher than 4 deg/s, is required for the telescopic camera to obtain unblurred high-resolution images. We have conducted conceptual studies of the tracking mirror and developed a breadboard model of the actuator. We report the initial performance results of the actuator and discuss future development/calibration plans for the tracking mirror.

ASTRO-2021-C025

「超高効率推進システム-100 キログラム級衛星への技術展開」

「Ultra High Volume Efficiency Propulsion System ? Extending The Technology to Hundred Kilogram Class Satellites」

* モンテイロ パドバン チアゴ, 川口 淳一郎(Patchedconics)

Abstract:

After delivering its first propulsion unit in 2019, Patchedconics has developed a system which makes use of space very efficiently. The Ultra High Volume Efficiency models are designed with all the components submerged inside the liquid propellant storage, which is not necessarily shaped like a sphere such as in most propulsion systems. This is possible due to the low vapour

pressure of the propellants used, which do not require special storage. Those units were first designed using a power-free gas generator. Now Patchedconics extends the design to a system which uses resistojet and active gas generator powered by a Lithium Polymer battery which has high energy storage capacity and discharge current. The batteries are for the propulsion unit only, they charge with low power and remain charged using a trickle method.

ASTRO-2021-C026

「宇宙望遠鏡における機械的振動に起因する光学収差の制御に関する研究」

「Study on Control System of Optical Aberration in Space Telescope by Mechanical Vibrations」

* 工藤 大輝（青学・院），菅原 佳城，武田 真和（青学）

Abstract:

Space telescopes are required to be larger and lighter. Therefore, space telescopes are subjected to mechanical vibrations that are caused by refrigerators and so on, which may affect the observation accuracy. In addition, it is not desirable to use multiple sensors because of thermal noise of the circuits for sensing system and reduction of the reliability due to complex system. This paper proposes a method to reduce the aberration using an image sensor instead of sensors to measure the deformation and vibration. Furthermore, since the proposed method requires a model of the space telescope, the modeling error is reduced by using an Unscented Kalman Filter. The effectiveness of the proposed method is confirmed by numerical analysis.