Indian Institute of Technology, Kanpur

Proposal for a New Course

1. **Course No:**

2. **Course Title: Fundamentals of Space Robotics**

3. **Per Week Lectures:** 3 (L), Tutorial: 0 (T), Laboratory: 0 (P), Additional Hours[0-2]: (A), Credits (L+T+P+A):

4. Duration of Course: 39 Hours

5. Proposing Department/IDP: Dept. of Intelligent System

   Other Departments/IDPs which may be interested in the proposed course:

   Aerospace Engineering, Mechanical Engineering & Electrical Engineering with dynamics and control specialization.

   Other faculty members interested in teaching the proposed course: Prof. Salahuddin Q, Prof. D. K Giri.

6. Proposing Instructor(s): Prof. Shakti S. Gupta and Prof. Anirban Roy

7. Course Description:

A) Objectives:

This course will cover fundamentals of robotics application in space-based systems. The course will start with the mathematical foundation of advanced kinematics, analytical & kinetic mechanics and robotic multi body dynamics. After that the course will concentrate on four different space robotic systems & applications – the orbiter, the lander and rover, spacecraft rendezvous and docking for applications like mating in ISS, in-orbit servicing and space debris clearance. Students will learn technologies like orbiter attitude and orbit control systems (AOCS) for different mission phases, attitude estimation using DTG, star tracker /4-pi sun sensor and magnetometer, sensor calibration; rendezvous and mating operation for two spacecrafts; strapdown inertial navigation system (SDINS) and camera or vision sensor-based terrain reference navigation (TRN) for lander & rover system, simultaneous localization and mapping (SLAM) for the rover system. The course will also cover space debris tracking algorithms using space-based radar and telescopic camera system & will focus on current research on robotic applications for space debris removal. There will be lots of numerical examples & assignments for students to understand the underlying concept of the course.

B) Contents (*preferably in the form of 5 to 10 broad titles)*:

(– Total Lectures) Course Instructor: Prof. Shakti S. Gupta

S. No	Broad Title	Topics	No. of Lectures
1	Mathematical Preliminaries	Review of vectors and second order tensors: indicial notations, basis transformations of tensors, invariants, eigenvalues and eigenvectors: spectral theorem.	4

2	Kinematics of rigid bodies	Rotation tensor: axis-angle formula, Euler angles, angular velocity of a rigid body, derivatives of vectors in rotating frames, angular acceleration, five-term acceleration formula.	**6**
3	Dynamics of rigid bodies	Free body diagram, computation of moment of inertia tensor for a rigid body, linear and angular momentum balance, computation of kinetic energy of a rigid body, introduction of holonomic and non-holonomic constraints, derivation of Lagrange's equation of motion, Lagrange multiplier. Problem solving using Newton-Euler and Lagrange's approach. Work-Energy and Impulse-Momentum principles.	**10**

(GNC Part of Space Robotics – Total 20 Lectures) Course Instructor: Prof. Anirban Roy

S. No	Broad Title	Topics	No. of Lectur
1	Introduction	• Fundamentals of Spacecraft Dynamics -1L • Spacecraft Kinematics: Attitude of a rigid body (Euler angle and Quaternion Algebra) – 2L • Difference between robotics vs Space robotic applications, Different types of space robotic applications – Orbiter, lander, rover, penetrators, mating or docking two spacecrafts or Spacecraft rendezvous operations for ISS or in-orbit servicing applications and Space debris clearance, Challenges and Evolution of Space Robotics - 1L	4L
2	Orbiter attitude and Orbit Control System (AOCS)	• Basics of S/C attitude control mechanisms (Spin stabilized system (single, Dual spin), 3-axis reaction wheel, or 2 axis momentum wheel, Magnetic torquer and Thrusters based actuation) – 1L • Orbiter attitude estimation using DTG, Star tracking, 4-pi sun sensor and magnetometer – 2L • Orbiter attitude and orbit control for different mission modes such as, suspended mode, launch mode, rate dumping mode, sun acquisition mode, normal mode, Imaging maneuver mode and orbit maneuver including station keeping mode (In plane and Out plane maneuvers) – 3L	6L
3	Lander and Rober Navigation and SLAM Algorithms	• Fundamentals of Strapdown inertial navigation system (SDINS) – 2L • Concept of Terrain aided vision-based navigation (visual odometry + Image registration) & Hybrid Navigation for lander & rover – 2L • Simultaneous localization and mapping for the rover - 1L	4L
4	Space Debris tracking and Robotic removal	• Fundamentals of Kalman Filter based tracking – 1 L • Data Association algorithm based multi-target tracking for Residual space objects (RSO) – Space radar & Telescopic camera-based bearing angle only tracking (BOT) – 1.5L • Space debris removal (Robotic Capture & ADR vehicles, Electrodynamic teathers, & Laser ablation) – 0.5L	3L

5	Rendezvous & Docking	• Purpose of spacecraft rendezvous and docking, Concept of relative inertial navigation for two spacecrafts – 1L • Phases of rendezvous and mating mission – Close range rendezvous, Terminal Approach, Final drifting and mating operations, Control and guidance algorithms for achieving rendezvous and mating – 2L	3L
MATLAB simulation exercises and assignments will be given for better understanding of the course.			

Total Lectures per week: 3

Reference:

1. Sidi, M.J., Spacecraft Dynamics and Control, Cambridge University Press, 1997
2. Wie, B., Space Vehicle Dynamics and Control, AIAA Education Series, 1998
3. Agrawal, B., Design of Geosynchronous Spacecraft, Prentice Hall, 1986
4. Hughes, P.C., Spacecraft Attitude Dynamics, John Wiley, 1986.
5. Noton, M., Spacecraft Navigation and Guidance, Springer 1998
6. Kaplan, M.H., Modern Spacecraft Dynamics and Control, John Wiley, 1976
7. Fehse W., Automated Rendezvous and Docking of Spacecraft, Cambridge University Press, 2003.
8. F. Landis Markley and J.L. Crassidis, “Fundamentals of spacecraft Attitude determination and Control, Springer 2014.
9. Y. Xu and T. Kanade, “Space Robotics: Dynamics and Control”, Springer 1992
10. Y. Wang, “Space Robotics,”, Springer, 2021
11. Y. Gao, “Space Robotics and Autonomous Systems: Technologies, advances and applications (Control, Robotics and Sensors)”, IET 2021
12. A. Ellery, “An Introduction to Space Robotics”, Springer 2000.

C)Pre-requisites, if any

1. Basic Dynamics & Control System Fundamentals.

D)Short summary for including in the Courses of Study Booklet:

8. **Recommended References:**

9. **Any other Remarks**

Dated: 22.07.2026
Proposer: Prof. Anirban Roy

Dated:
DUGC/DPGC Convener:

The course is approved / not approved

Chairman SUGC/SPGC:
Dated: