# SPACECRAFT AUTONOMY

## MINI PROJECT REPORT

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**BACHELOR OF TECHNOLOGY (AI&DS)**

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# CERTIFICATE

This is to certify that **ms.Srushti Bhosale, ms.Krushnai Burpalle, ms.Aarya Gaikwad** has successfully submitted her Mchine Learning mini project report to the Department of AI&DS , VPKBIET, Baramati,on-17-10-25
**"Spacecraft Autonomy"** during the academic year 2025-2026 in the fully fulfilment towards completion of third year of **Bachelor of Technology** in **Artificial Intelligence & Data Science.**

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# Abstract

The growing complexity of space missions and the demand for real-time decision-making have driven the advancement of autonomous spacecraft systems. This project explores the development and implementation of spacecraft autonomy, focusing on onboard decision-making, fault detection and recovery, navigation, and mission adaptability. By leveraging artificial intelligence, machine learning, and advanced control algorithms, autonomous spacecraft can perform critical functions with minimal ground intervention, increasing mission efficiency and reducing operational costs. This report presents an overview of key technologies, system architectures, and case studies demonstrating the benefits and challenges of autonomous systems in space exploration. The findings highlight the importance of robust autonomy in enabling deep space missions, satellite constellations, and interplanetary exploration.

# Contents

# Chapter 1

# Introduction

As space missions become increasingly complex and distant, the need for autonomous spacecraft systems has grown significantly. Traditional spacecraft operations rely heavily on ground control for decision-making, navigation, and fault management. However, the limitations of communication delay, especially in deep space missions, make real-time human intervention impractical. To overcome these challenges, the integration of autonomy into spacecraft systems has emerged as a critical solution. Spacecraft autonomy refers to the ability of a spacecraft to perform tasks, make decisions, and respond to unexpected events without direct human input. These capabilities are made possible through advancements in artificial intelligence (AI), machine learning (ML), sensor technologies, and control systems. Autonomous spacecraft can conduct scientific operations, manage resources, detect and correct faults, and adapt to dynamic environments, all while reducing the need for constant ground supervision. This report aims to explore the principles, technologies, and applications of spacecraft autonomy. It discusses the architecture of autonomous systems, current and emerging technologies enabling autonomy, and real-world examples from recent missions. The goal is to highlight how autonomous spacecraft are revolutionizing space exploration by enhancing mission efficiency, reliability, and scalability.

# Chapter 2

# Literature Review

The concept of spacecraft autonomy has evolved over several decades, driven by the need to reduce human intervention in increasingly complex and distant space missions. This section reviews key research contributions, mission case studies, and technological developments relevant to autonomous spacecraft systems.

**1. Foundational Work in Autonomy:** Early studies in the 1980s and 1990s focused on incorporating basic decision-making and fault detection capabilities into spacecraft. The NASA Deep Space One mission (1998) is considered a landmark in autonomous space exploration. It demonstrated autonomous navigation and health management using an onboard AI system called Remote Agent. According to Muscettola et al. (1997), Remote Agent was among the first systems to plan and execute mission tasks independently, marking a significant step forward.

**2. AI and Machine Learning Applications:** Recent advancements in AI and machine learning have significantly improved the capabilities of autonomous systems. Technologies such as reinforcement learning, deep learning, and computer vision are now being explored for spacecraft guidance, object detection, and anomaly prediction. For instance, Wu et al. (2020) proposed a deep learning model for real-time fault detection in satellite systems, demonstrating increased reliability compared to traditional rule-based systems.

**3. Autonomous Navigation and Guidance** Autonomous navigation has become essential, especially for planetary exploration missions. NASA's Mars rovers, including Curiosity and Perseverance, use visual odometry and terrain-relative navigation to traverse challenging landscapes. According to Maimone et al. (2007), the autonomous driving software on Curiosity significantly reduces the need for manual path planning from Earth, allowing the rover to cover greater distances safely.

**4. Autonomous Mission Planning and Scheduling** Autonomous planning systems enable spacecraft to generate and adjust mission plans in response to changing environments or unexpected events. Systems like the Autonomous Sciencecraft Experiment (Chien et al., 2005) demonstrated onboard science data processing and decision-making, allowing satellites to prioritize observations and reduce data transmission costs.

**5. Challenges Identified in Literature** Despite major progress, the literature identifies several challenges in achieving full autonomy. These include limited computational resources onboard spacecraft, the need for reliable verification and validation of autonomous systems, and ensuring resilience against faults in unpredictable space environments. The European Space Agency (ESA) and NASA both emphasize the importance of building trust in autonomous operations through extensive testing and simulation (ESA, 2021).

# Chapter 3

# System Architecture

An **Spacecraft Autonomy** Autonomous spacecraft rely heavily on software systems to perform tasks without constant input from mission control. These software components work together to make decisions, plan actions, monitor health, and manage data. The main parts of the software architecture are:

**1. Decision-Making System** This is the "brain" of the spacecraft. It decides what the spacecraft should do based on its goals and current status. It can:

- **Choose between different tasks:** (e.g., collecting data, charging batteries)
- **React to changes or problems:** (e.g., low power, obstacle ahead)

  Re-plan the mission if needed

**2. Planning and Scheduling Software** This software creates a timeline of tasks for the spacecraft. It:
Organizes tasks in the best possible order
Updates the plan if something unexpected happens
Makes sure resources (like power or time) are used efficiently

**2. Design Principles for AACS Architecture** Navigation and Control Software
This system helps the spacecraft know where it is and how to move safely. It includes:
Autonomous Navigation: Calculates the spacecraft's location using sensors.
Path Planning: Finds safe and efficient routes.
Attitude Control: Points the spacecraft in the right direction.

# Chapter 4

# Methodology

The methodology for this project involved a structured approach to studying spacecraft autonomy, with a primary focus on software systems. The process began with an in-depth literature review of academic research, mission reports, and technical documentation related to autonomous spacecraft operations. This helped identify the key software components used in autonomy, including decision-making systems, planning and scheduling, navigation and control, fault detection and recovery (FDIR), and data management. A conceptual software architecture was then developed to illustrate how these components interact and function together onboard a spacecraft. Various tools and technologies commonly used in space software—such as real-time operating systems, AI libraries, and simulation platforms—were also explored to understand their role in autonomous operations. Where applicable, simple logic-based scenarios were designed or reviewed to simulate how autonomous systems respond to real-time events or anomalies. This methodology provided a clear understanding of the design, function, and importance of autonomy in modern space missions, and laid the groundwork for further analysis and recommendations in the report. This project adopted a research-based and conceptual design approach to study the software systems behind spacecraft autonomy. The first step involved conducting a comprehensive literature review to understand how autonomous systems have been applied in past and current space missions. Sources included scientific journals, space agency publications (such as NASA and ESA), and case studies from missions like Deep Space One, Mars rovers, and autonomous Earth observation satellites. This helped identify the main functional areas of autonomous software, including decision-making algorithms, task planning and scheduling, fault detection and recovery (FDIR), autonomous navigation, and onboard data management. Based on this foundation, a simplified software architecture was designed to conceptually model how these components interact to achieve full or partial autonomy. The architecture outlined data flow, software responsibilities, and communication between modules. In addition to studying system structure, commonly used technologies and platforms were reviewed, such as embedded systems, artificial intelligence frameworks, and real-time operating systems used in space applications. Where possible, small-scale logic or flowchart models were created to demonstrate how an autonomous spacecraft might respond to events like system faults, sensor input changes, or mission plan updates. This methodology provided both theoretical knowledge and practical insight into the design and behavior of autonomous spacecraft software systems, forming the basis for further analysis and discussion in report.

## Conclusion

Spacecraft autonomy is becoming increasingly essential as missions venture farther from Earth and grow in complexity. This project explored the software systems that enable autonomous operations, focusing on key components such as decision-making, task planning, navigation, fault detection, and data management. Through the study of real missions, existing research, and conceptual system design, it is evident that autonomous software significantly enhances the efficiency, reliability, and safety of space missions by reducing the need for constant ground control. As technology advances, especially in artificial intelligence and onboard computing, future spacecraft will become more intelligent and capable of making complex decisions in real time. Overall, spacecraft autonomy represents a major step forward in the evolution of space exploration, making long-duration and deep space missions more feasible and effective.

# Chapter 5

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