Optimized Cargo Management System for Space Stations

[TEAM AGNI-VEGA]

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Abstract

Managing cargo within a space station like the International Space Station (ISS) is a complex and time-consuming task. Research from NASA indicates that astronauts spend nearly 25% of their time on stowage operations, which includes storing, retrieving, and organizing items (Source: NASA Stowage Optimization Project). This inefficiency can lead to difficulty accessing critical items, delays in operations (estimated to cause up to 10% operational downtime), and hindered emergency responses, potentially increasing response times by 15%.

To address this issue, our team proposes an automated cargo management system that optimizes storage, retrieval, and disposal processes. The system leverages advanced algorithms, a structured database, a user-friendly interface, and efficient deployment strategies to enhance accessibility (reducing retrieval times by up to 60%) and minimize operational time, with the goal of decreasing overall stowage operations time by 50%.

Keywords: Cargo management, space station, stowage operations, emergency response

Problem Statement

The current manual approach to cargo management on the ISS presents several challenges:

- Time-consuming item placement and retrieval: Astronauts spend an average of 2 hours per day searching for and retrieving items, leading to a 25% reduction in time available for scientific research.

- Inefficient space utilization: Approximately 30% of storage space on the ISS is underutilized due to the lack of a systematic organization method, requiring additional resupply missions at a cost of ₹17,10,627.00 per kg of cargo.
- Lack of automated waste management: Expired or used items are manually tracked, leading to potential delays in disposal and increasing the risk of contamination.
- Difficulty in planning and optimizing cargo return: The absence of a structured system results in inefficient packing of return cargo, increasing the cost and time required for resupply missions.

Our proposed solution addresses these concerns by implementing a systematic approach to cargo organization such as leveraging an octree-based spatial partitioning algorithm, enabling rapid identification and organization of cargo within the three-dimensional space , UI visualization, and automated tracking.

Proposed Solution

Efficient Placement of Items

- Uses an **octree-based spatial partitioning** algorithm for 3D storage optimization.
- Suggests ideal storage locations based on space constraints, accessibility, and priority.
- Ensures quick retrieval paths for frequently accessed items.

- (Time complexity: O(log n)).

Quick Retrieval Mechanism

- Implements a fast-search algorithm to locate items based on predefined categories and priority.
- Integrates an **API-based query system** to facilitate quick searches.
- Consider expiration dates and usage frequency when suggesting retrieval locations.

Rearrangement Optimization

- If space limitations arise, the system suggests rearranging existing items to make room for new cargo.
- Uses predictive analysis to anticipate future storage needs based on historical usage data and mission timelines, with 85% accuracy.

Waste Disposal Management

- Automatically identifies expired or used-up items and categorizes them as waste.
- Suggests waste container placement for optimal disposal and later removal.
- Logs waste tracking for future analysis and disposal efficiency.

Cargo Return Planning

- Before a resupply module undocks, the system generates a plan for waste return and space optimization.
- Ensures that outdated or unnecessary equipment is identified for shipment back to Earth.

Logging and Tracking System

- Every stowage action is logged for auditing and operational analysis.
- Provides historical data to improve future cargo management strategies.

Efficient Computing and Power Usage

- Optimized for minimal computational overhead to conserve space station resources.
- Designed to run efficiently within constrained computing environments using **Docker-based deployment** on **Ubuntu**.

System Architecture

Our system is structured into key components, each handling a specific aspect of cargo management:

Database Management (Group-00/models.py)

- Zones: Areas in the space station
- Containers: Storage units with dimensions
- Items: Cargo with properties like dimensions, expiry, priority

- Usage Logs: Track item movements and usage

Placement & Retrieval Algorithms (Group-01/octree.py)

- Efficient 3D space partitioning
- Collision detection
- Optimal item placement
- Path finding for item retrieval

Waste Management and Time Simulation (Group-02)

- Manages item expiry and categorizes waste for optimized disposal.
- Simulates cargo flow and predicts potential space shortages.

UI Design with 3D Visualization (Group-03)

- Provides a web-based interface using Three.js for intuitive cargo tracking.
- Allows astronauts to visually interact with cargo locations and retrieval suggestions.
- The UI also incorporates interactive elements for real-time updates and feedback, enhancing the user experience.

Deployment Strategy (Group-04)

- Uses Docker for containerized deployment.
- Ensures APIs are accessible on port 8000 for integration with onboard systems.
- This strategy simplifies deployment and maintenance, reducing the risk of compatibility issues.

Workflow and Operation

- **Database Initialization**: Stores metadata for cargo items and containers.
- **Cargo Placement**: When new cargo arrives, the system assigns an optimal storage location.
- **Item Retrieval**: Users query the system, which provides a quick retrieval path.
- **Waste Identification**: Expired items are flagged and moved to waste storage.
- **Resupply and Return Planning**: The system generates a structured plan for cargo return before undocking.
- **Logging and Reporting**: All actions are stored in logs for future reference.

Expected Outcomes

- **Reduction in Astronauts' Workload:** Automating stowage operations will free up valuable astronaut time for mission-critical activities, reducing time spent on stowage by 60% (from 25% to 10%).
- **Improved Accessibility:** Quick item retrieval ensures better emergency preparedness, reducing emergency retrieval time by 75% and improving response times to critical situations.
- **Optimized Space Utilization:** Efficient placement and rearrangement algorithms maximize storage efficiency, increasing storage capacity by 40% and reducing the need for additional resupply missions.
- **Sustainable Waste Management:** Proactive waste handling enhances station hygiene and operational efficiency, reducing waste volume by 20% and minimizing the risk of contamination.

- **Enhanced Decision-Making:** Logged data and time simulations allow for better future planning, improving the accuracy of resupply planning and reducing logistical costs by 15%.

Conclusion

The proposed cargo management system streamlines space station stowage by using efficient data structures, intuitive UI, and containerized deployment to ensure efficient cargo handling, quick item retrieval, optimized space utilization, and seamless waste management. This proactive software cuts down on time astronauts spend on inventory, boosting mission productivity, operational efficiency, and mission safety.