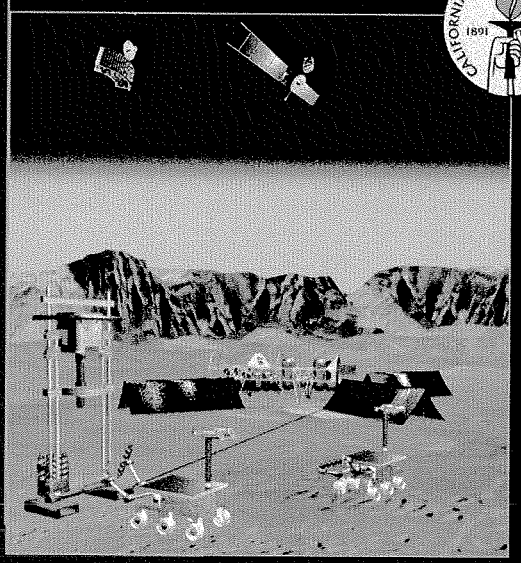
Technologies for Complex Systems Automation and Autonomy in Deep Space Exploration



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Outline

- MDS: Reusable core software system for embedded real-time control
- ASPEN: Automated Planning and Scheduling ENvironment
- BEAM/SHINE: Real-time Diagnosis and Prognosis of Instrumented Systems
- CAE: Common Automation Engine
- Diamond Eye: Data Mining Images for Discovery

Mission Data System: MDS

The Challenge

A new era of

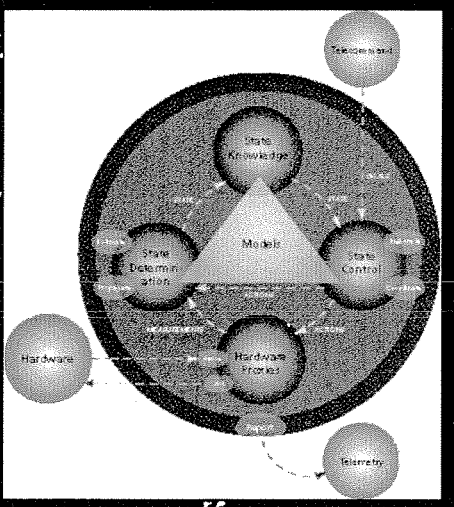
- Frequent launches
- Operations in dynamic environments
- System and software system design
- Cost effective …and higher quality

How could we tackle these challenges and leverage our solution across multiple missions and applications?

Mission Data System: MDS

The Solution

MDS provides a reusable, reliable core framework, components, technology, and engineering methodology at the heart of complex embedded real-time control Systems.



Assimilates generations of JPL domain knowledge

Flight and ground applicability, as well as generality to a wide variety of embedded control systems, offer broad options for reuse and rapid development

Mission Data System: MDS

Readiness & Applications

MDS is designed, rapidly maturing, and slated for testing in critical JPL applications

Patent-pending

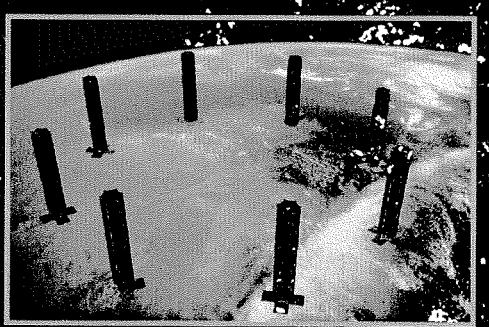
Licensing and co-operative development activities are already underway with several industry partners

- Embedded real-time processors
- Autonomous control systems
- Automobile control systems
- Civil and military avionics
- Next-generation home appliances
- Physical plant operations
- Manufacturing automation

ASPEN: Automated Planning and Scheduling ENvironment

The Challenge

How to reliably perform complex, multi-asset operations in an increasingly dynamic environment with a manageable human operations impact



The Solution

ASPEN:
Automated Planning and Scheduling ENvironment

Plans → Operations planning is the solution

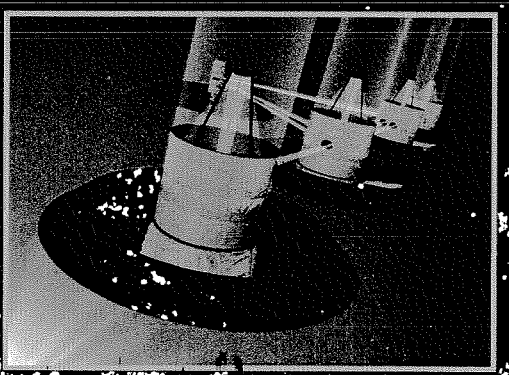
ASPEN automatically generates plans of activities to achieve desired goals while respecting operations constraints involving states, resources and timing.

Industry Applications

ASPEN:
Automated Planning and Scheduling ENvironment

Possible Industry Applications:

- Resource management
- Complex scheduling tasks
- Maintenance scheduling
- Workflow scheduling
- Production planning
- Operations planning
- Manufacturing planning
- Staffing planning



ASPEN:
Automated Planning and Scheduling ENvironment

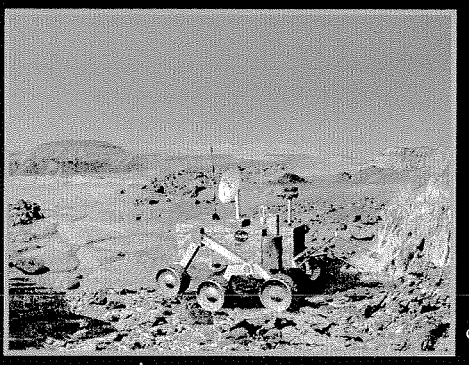
Readiness

ASPEN has been applied to ground-based and onboard planning problems such as:

- antenna ground station automation,
- autonomous spacecraft,
- rovers and
- unpiloted aerial vehicles.

Readiness:

- Maintenance scheduling
- ASPEN is currently available for licensing agreements.

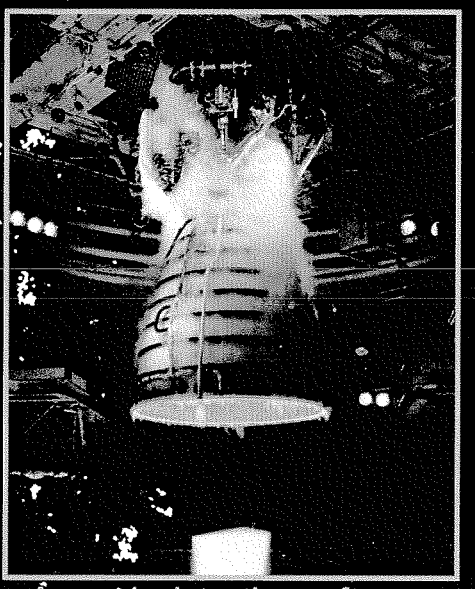


BEAM/SHINE: Real-time Diagnosis and Prognosis of Complex Systems

The Challenges

To find and isolate anomalies in virtually any instrumented system and isolate them in both time and space, *without* false alarms.

To detect system degradation prior to failure for increased safety and interoperability.



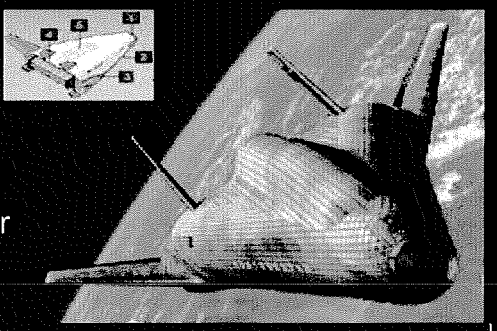
Anomaly detection software used for the Space Shuttle Main Engine

BEAM/SHINE: Real-time Diagnosis and Prognosis of Complex Systems

The Solution

BEAM/SHINE:

- Is an end-to-end method of data analysis intended for real-time fault detection and characterization
- Finds degradation and changes in a system and isolates those changes in both space and time
- Provides a generic system analysis capability for application to highly automated systems
- Detects un-modeled and unanticipated events with near zero false alarms
- Has state-of-the-art inference speed (> 33,000,000 rules per second)

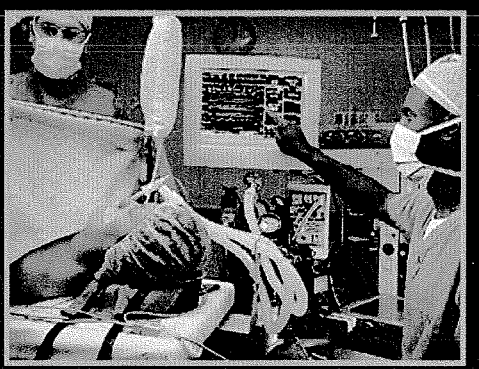


BEAM/SHINE: Real-time Diagnosis and Prognosis of Complex Systems

Industry Applications

Possible Industry Applications:

- Vehicle health management
- Real-time diagnosis/prognosis
- Tool wear analysis
- Financial analysis
- Factory automation
- Patient monitoring
- Genetic modeling
- Designing for safety and reliability



BEAM/SHINE: Real-time Diagnosis and Prognosis of Complex Systems

Readiness

BEAM/SHINE has been delivered to numerous NASA and commercial partners. Applications include:

- Lockheed Joint Strike Fighter (JSF) demonstration
- Space Shuttle Main Engine diagnosis
- Cancer classification system
- Unmanned aerial vehicles
- Factory automation

Readiness:

BEAM/SHINE has already been licensed and is currently available for further licensing.

Common Automation Engine: CAE

The Challenge

To improve spacecraft and satellite communication reliability

To increase antenna utilization through reduced downtime

To allow operators to focus on more specialized tasks

Common Automation Engine: CAE

The Solution

CAE is an automation system that integrates two key components: planning (ASPEN) and diagnosis (BEAM/SHINE).

CAE increases operational reliability and resource utilization by rapidly and accurately configuring the system and responding to anomalies through autonomous:

- sequence generation and execution
- system monitoring and anomaly detection
- efficient response to anomalies

CAE aides the operator by automating mundane, time-consuming, and error-prone tasks, thus making the operator available for valuable highly skilled tasks

Common Automation Engine: CAE

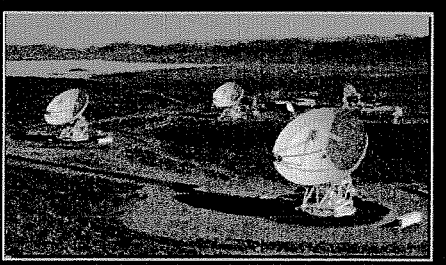
Readiness & Applications

Readiness:

- Engineering prototype built on:
  - Mature planning, scheduling and execution component (ASPEN/CASPER/CLEaR)
  - Mature fault detection and isolation component (BEAM/SHINE)

Possible Industry Applications:

- Robotic Automation
- Control Center Automation
- Process Management
- Factory Automation



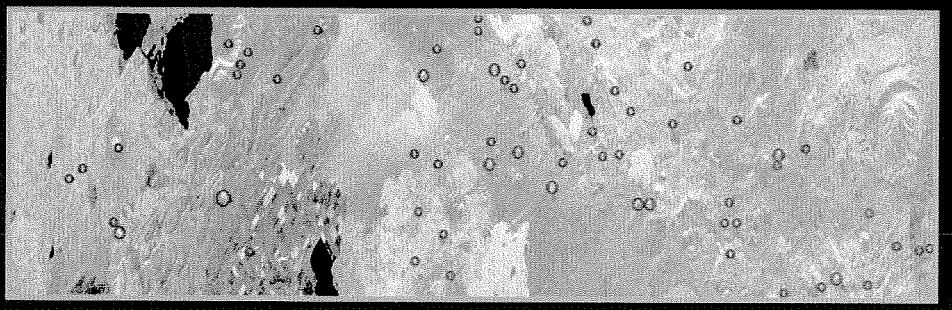
Diamond Eye: Data Mining Images for Discovery

The Challenge

Given an example target, search large image data sets for targets

Software used must be:

- Reliable/accurate (high detection rate, low false alarm rate)
- Easy to use
- Fast

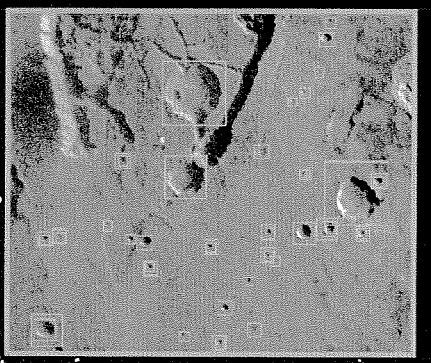


Diamond Eye: Data Mining Images for Discovery

The Solution

Using machine learning and computer vision techniques, develop algorithms that can be trained and customized by users looking for particular types of features

The approach is to detect features using a technique that enables matched filtering over a continuous scale space

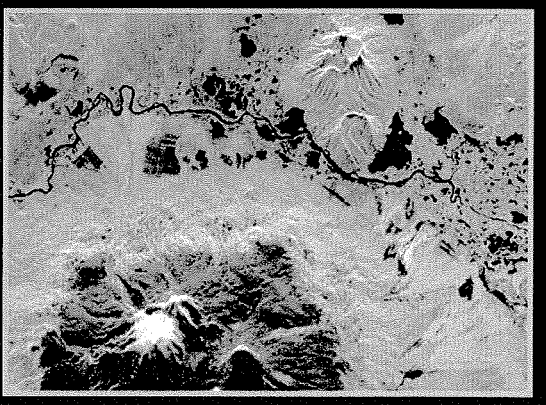


Diamond Eye: Data Mining Images for Discovery

Readiness & Applications

Diamond Eye is currently applied in scientific domains:

- lava cones in SAR imagery of Earth
- craters on Mars
- craters on the Moon
- boulders on Eros
- volcanoes on Venus



Other possible applications:

- surveillance
- usage pattern studies
- image database retrieval

Conclusion

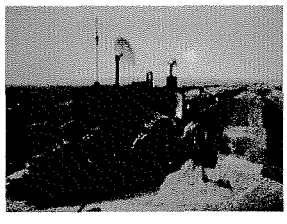
These technologies, while developed for our space exploration mission, have substantial applicability and relevance to manufacturing and commercial products.

We stand ready to help you benefit from our hard-won knowledge

Licensing
Partnering
Co-development
… many more options available

Automated Planning and Scheduling ENvironment: ASPEN

Technology Opportunity



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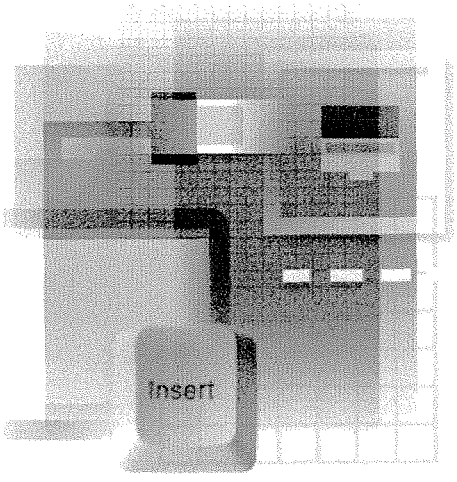


Objective

The National Aeronautics and Space Administration seeks companies to commercialize an advanced planning and scheduling software system (ASPEN). This system significantly decreases the time needed to generate plans while increasing the quality of the plans.

Product Profile

ASPEN automatically generates plans of activities to achieve desired goals while respecting operations constraints involving states, resources, and timing.

ASPEN has been applied to ground-based and onboard planning problems such as: antenna ground station automation, autonomous spacecraft, rovers, and unpiloted aerial vehicles.

Potential Applications

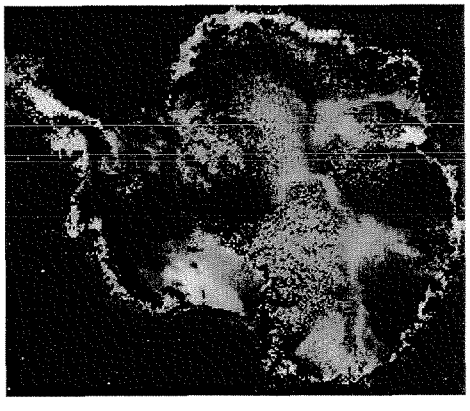
- Resource management
- Complex scheduling tasks
- Maintenance scheduling
- Workflow scheduling
- Production planning
- Operations planning
- Manufacturing planning
- Staffing planning

Benefits

- Reducing operation cost
- Flexible, reusable application framework
- Easy to use modeling language
- Plan optimization
- Real-time re-planning and response
- Plan validation

Technology Deployment

ASPEN automated the mission planning process for the Modified Antarctic Mapping Mission, a joint mission between NASA and the Canadian Space Agency that operated from November to December of 2000 on RadarSAT. Human planners selected desired observations from a large set of opportunities. The ASPEN system automatically generated the data downlink schedule for these observations, expanded the observations and downlinks into a detailed mission plan, and verified that this detailed plan respected all of the spacecraft operating constraints. The system reduced the mission planning effort to about eight workweeks as opposed to over a work-year for the first Antarctic Mapping Mission, which was of comparable complexity and planned manually.



Common Automation Engine: CAE

Technology Opportunity

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Objective

The National Aeronautics and Space Administration seeks companies to commercialize an advanced Common Automation Engine (CAE) for robotic and process control. This system is scalable for use at multiple levels in a hierarchical control environment.

Product Profile

CAE is a scalable automation engine comprising a state-of-the-art activity planning, scheduling and execution system (based on ASPEN) and a fault detection and isolation system (based on BEAM/SHINE).

Through the coupling of the planning and diagnosis systems, CAE can more quickly and accurately respond to real-time system measurements. Types of responses consist of the generation, execution, monitoring and repair of command sequences for robotic automation.

CAE has been applied to antenna ground station automation. A variant of this architecture has been applied to un-piloted aerial vehicles, while components have been applied to rovers, spacecraft and aircraft.

Potential Applications

- Robotic Automation
- Control Center Automation
- Process Management
- Factory Automation

Benefits

- Reducing operation cost
- Flexible, scalable, reusable application framework
- Easy to use modeling language
- Control sequence generation
- Control sequence execution
- Fault detection
- Fault isolation
- Real-time re-planning & response
- System monitoring
- Sensor archiving
- Archive playback (offline analyses)

Technology Deployment

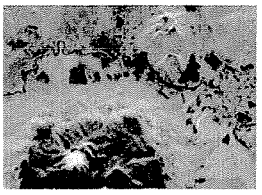
CAE demonstrated autonomous configuration and downlink communication with several deep space spacecrafts during the summer of 2002.

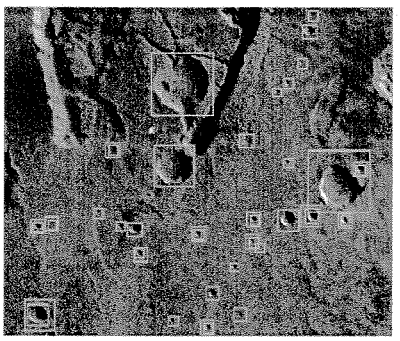
CAE demonstrated improved system reliability that facilitated increased antenna utilization by rapidly and accurately configuring the system and responding to anomalies. In part, this performance improvement comes from automation of time-consuming, mundane, error-prone tasks, which frees the operator for more valuable, specialized tasks.

These communication passes were performed in an autonomous fashion without operator intervention. In contrast, current operations require human monitoring of five different display screens, tens of subsystems, and manual input of hundreds of commands.

Diamond Eye: Data Mining Images for Discovery

Technology Opportunity





Introduction

In collaboration with the Southwestern Research Institute, NASA's Jet Propulsion Laboratory (JPL) has developed Diamond Eye, a software product that enables both scientists and remote systems to find, analyze, and catalog spatial objects and dynamic events in large scientific datasets and real-time image streams.

Product Profile

The fundamental technical challenge is to determine what mathematical processing should be applied to the low-level, pixel representation contained in a raw image (or image sequence) in order to identify spatial objects, such as volcanoes and craters, and dynamic events, such as eruptions and satellite motion. The Diamond Eye algorithm development effort is directed toward providing robust solutions for this problem in the face of varying degrees of a priori knowledge.

Potential Applications

Many science applications stand to benefit from the existence of robust recognition and mining algorithms. Examples of automated feature detection and analysis include:

- impact craters
- volcanoes
- sand dunes
- satellites (i.e. moons)

Other application opportunities include:

- face recognition
- image retrieval

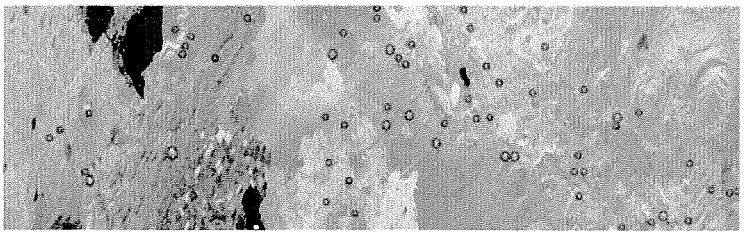
Benefits

Key benefits of the Diamond Eye architecture are:

- adaptive recognition based on continuously-deformable templates,
- the design promotes trial evaluation of advanced data mining and machine learning techniques by potential new users,
- the system facilitates closer collaborations between algorithm developers and domain experts.

Architecture

The Diamond Eye system uses a distributed software architecture that enables users (scientists) to analyze large image collections by interacting with one or more custom data mining servers via a Java applet interface. The server, which acts as a centralized coordinator, takes requests from users and interfaces with image sources, algorithms, and databases to satisfy user requests. Each server is coupled with an object-oriented database and a computational engine such as a network of high-performance workstations. The database provides persistent storage for user and system data and supports querying of the "mined" information. The computational engine provides parallel execution of expensive image processing, object recognition, and query-by-content operations.



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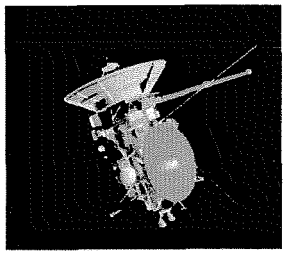
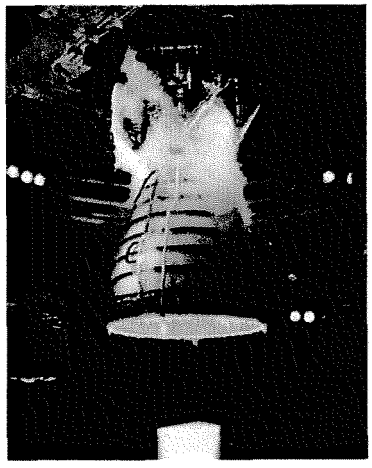
Real-time Diagnosis and Prognosis of Complex Systems

Technology Opportunity





Objective

The National Aeronautics and Space Administration seeks companies to commercialize an autonomous vehicle health management system called BEAM/SHINE. This technology provides real-time diagnosis and prognosis of any instrumented system.

Product Profile

This technology provides a unique capability to fuse and simultaneously analyze all system-observable data. BEAM/SHINE is an ultra-sensitive method to *find degradation and changes in nearly any instrumented system and to isolate those changes* in both space and time with near zero false alarms.

BEAM/SHINE presents a viable onboard technology alternative to traditional, labor-intensive methods of spacecraft and aircraft health assessment.

Potential Applications

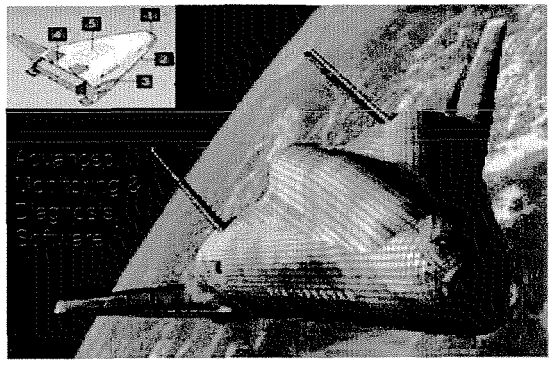
- Vehicle health management
- Real-time diagnosis/prognosis
- Factory automation
- Financial analysis
- Genetic modeling
- Patient monitoring
- Designing for safety and reliability

Benefits

- Increases safety
- Improves reliability
- Reduces operational costs
- Predicts degradation prior to system failure
- Eliminates need for scheduled maintenance
- Provides complete diagnostic assessment for the spacecraft, aircraft, and other complex systems with near zero false alarms

Technology Deployments

- Power and Pyrotechnics Subsystem Simulation
- Cassini Flight Software Development System
- X-33 Aerospike Engine Test
- X-33 LOX Tank Structures Test Data
- Space Shuttle Machine Engine test and Flight Data
- Unmanned aerial vehicles
- Lockheed Joint Strike Fighter (JSF)
- Spacecraft Health Automatic Reasoning Pilot (SHARP)
- X-33 Avionics Flight Experiment (AFE)
- Cancer Classification System
- Robotic Endoscopic Surgery Control System
- Deep Space Network Operations
- Financial Modeling and Simulation
- Genetic Sequence Pattern Matching



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