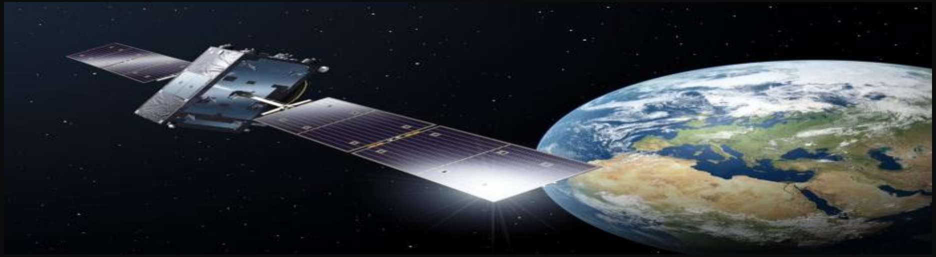
Toward Intelligent Health Monitoring System for Space Missions



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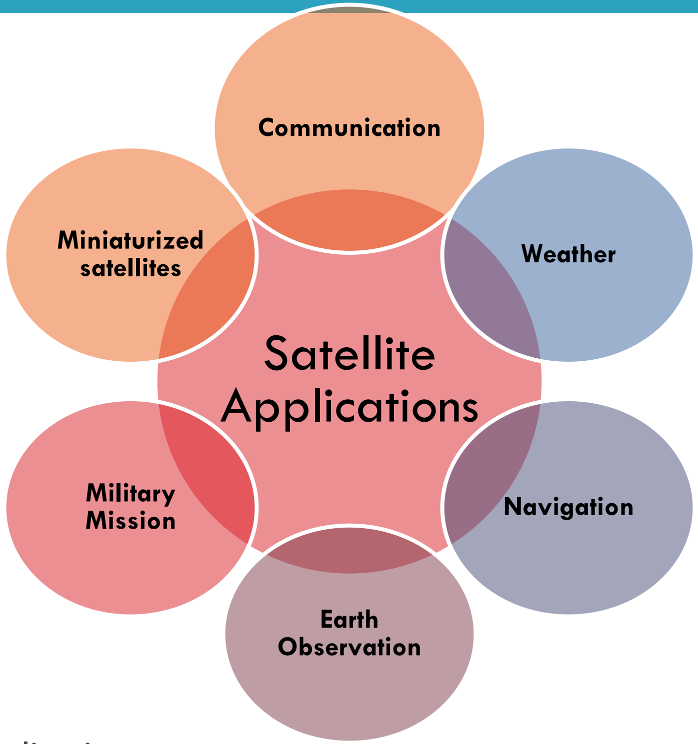
Overview

- Importance of Space Technology
- Major Challenges for Space Mission
- Telemetry Satellite Data
- Health Monitoring System
- Failure Detection and Recovery

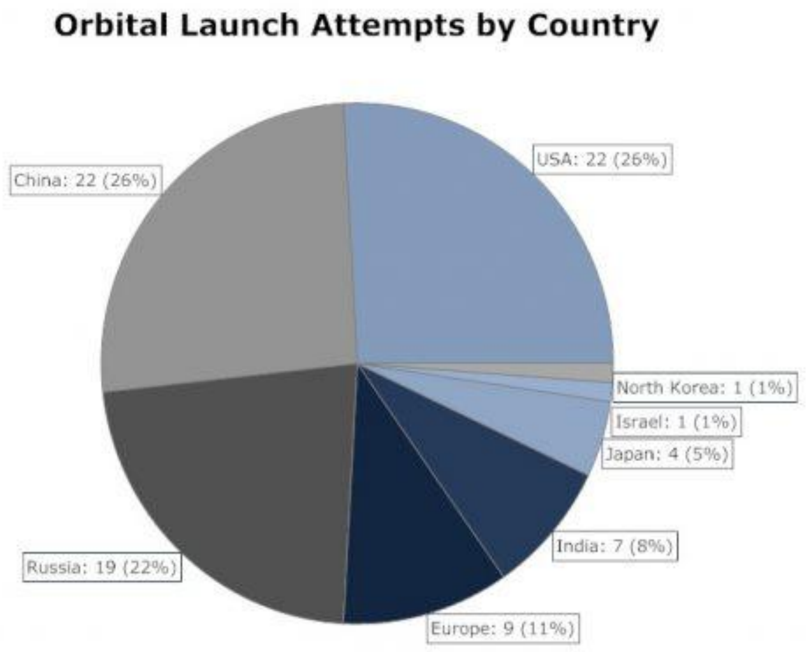
Importance of Space Technology

- Space technology has become an integral part of our daily lives. Many common everyday services such as weather forecasting, remote sensing, GPS systems, satellite television and communication. Also, Space systems have an important role to play in supporting the assessment, early warning, surveillance and response to threats, ranging from natural disasters (earthquakes, tsunamis, geomagnetic storms) to major health risks (pandemics, air pollution).



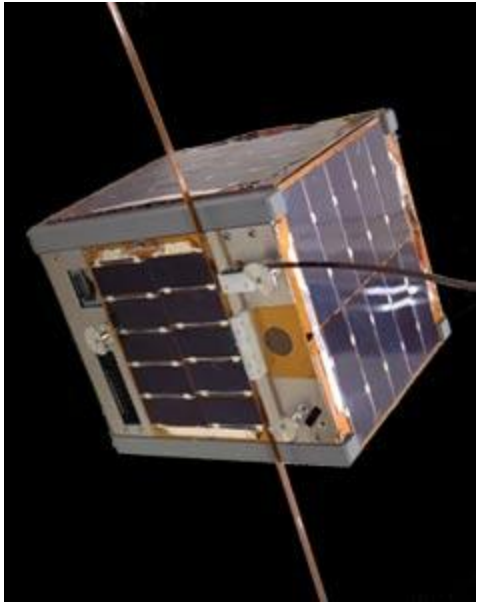
2016 Space Launch Statistics

- The year 2016 saw a total of 85 known orbital launch attempts from space ports in nine different countries. 2016 ranks third in the current century in terms of the total number of orbital launch attempts, short to 92 attempts in 2014 and 87 in 2015.



CubeSat

The miniaturized satellites are the satellites have low mass and small physical size, like CubeSat less than 1kg. Uses typically involve experiments which are used to demonstrate spacecraft technologies that are targeted for use in small satellites or that present questionable feasibility and are unlikely to justify the cost of a larger satellite.



Year	Number of CubeSats	Year	Number of CubeSats
2000	5	2008	8
2001	1	2009	11
2002	1	2010	15
2003	6	2011	12
2004	0	2012	23
2005	3	2013	84
2006	20	2014	118
2007	7	2015	564

Table: Annual number of CubeSats launched

Failure in Space

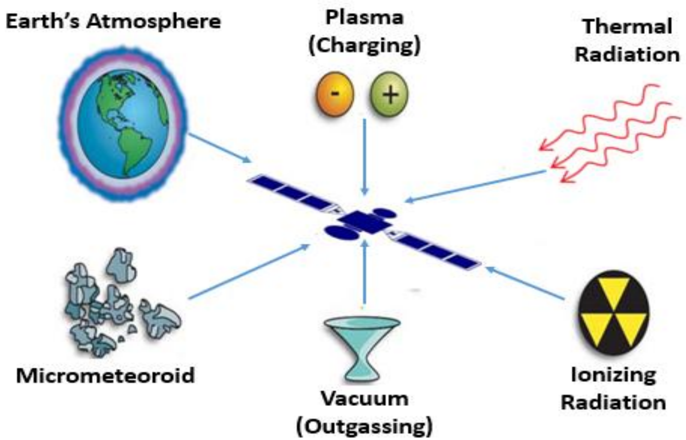
- The major obstacle to the progress of space exploration and utilization of space for human benefit is the safety.
- Hundreds of people and billions of dollars were lost because of lots of space system failure cases. Between 1959 and 1995 there have been 166 accidents happened in manned space crafts flights out of total 249 (about 67%). As of 2016 saw two failed launches on missions operated by China and Russia.

Space Shuttle Challenger disintegrated 73 seconds after its 1986 launch resulting in the death of all seven crew members.

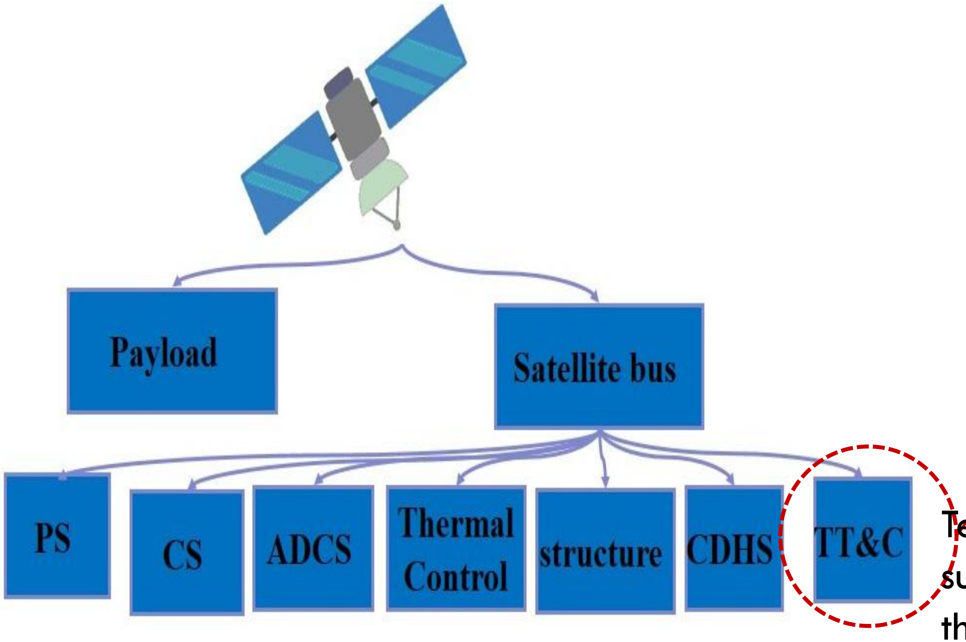
Space Environment Hazards

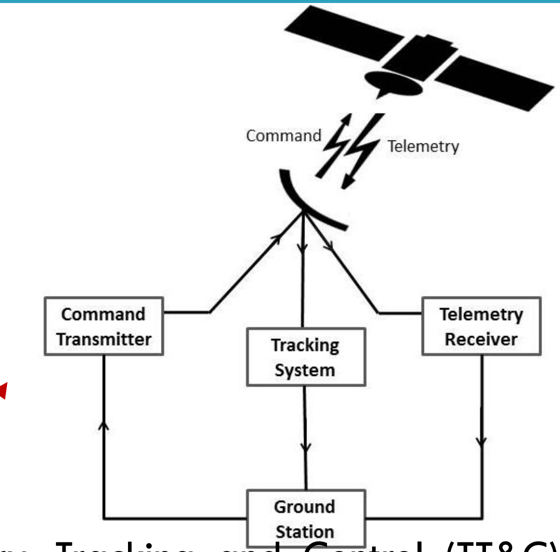
- Space systems fulfil their mission in a very special, harsh, and challenging environment. So it is practically impossible to completely eliminate the possibility of anomalies or faults.

Space Environment Effects on Satellites



Satellite Architecture

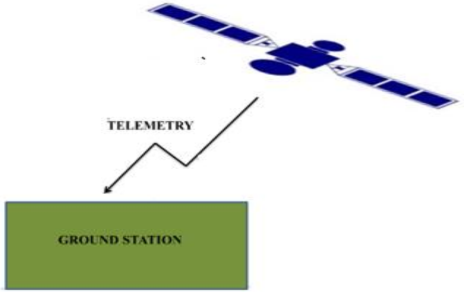


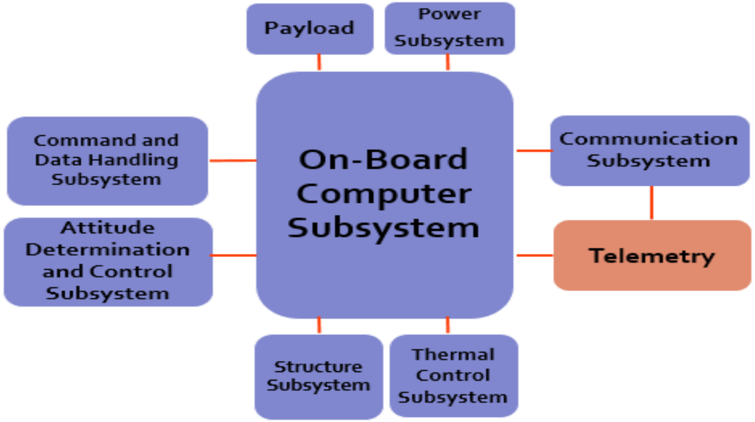


Telemetry, Tracking and Control (TT&C) is the brain subsystem of satellite provides a connection between the satellite itself and the facilities on the ground. The purpose of the TT&C function is to ensure the satellite performs correctly.

Telemetry Data

Telemetry is the downlink from satellite to ground station, is the collection of measurements and onboard instrument readings required to deduce the health and status of all of the satellite subsystems in the spacecraft bus and the payload. The TT&C subsystem must collect, process, and transmit this data from the satellite to the ground. It is a very important task in the operation of artificial satellites to monitor the health state of the system and detect any abnormal behavior



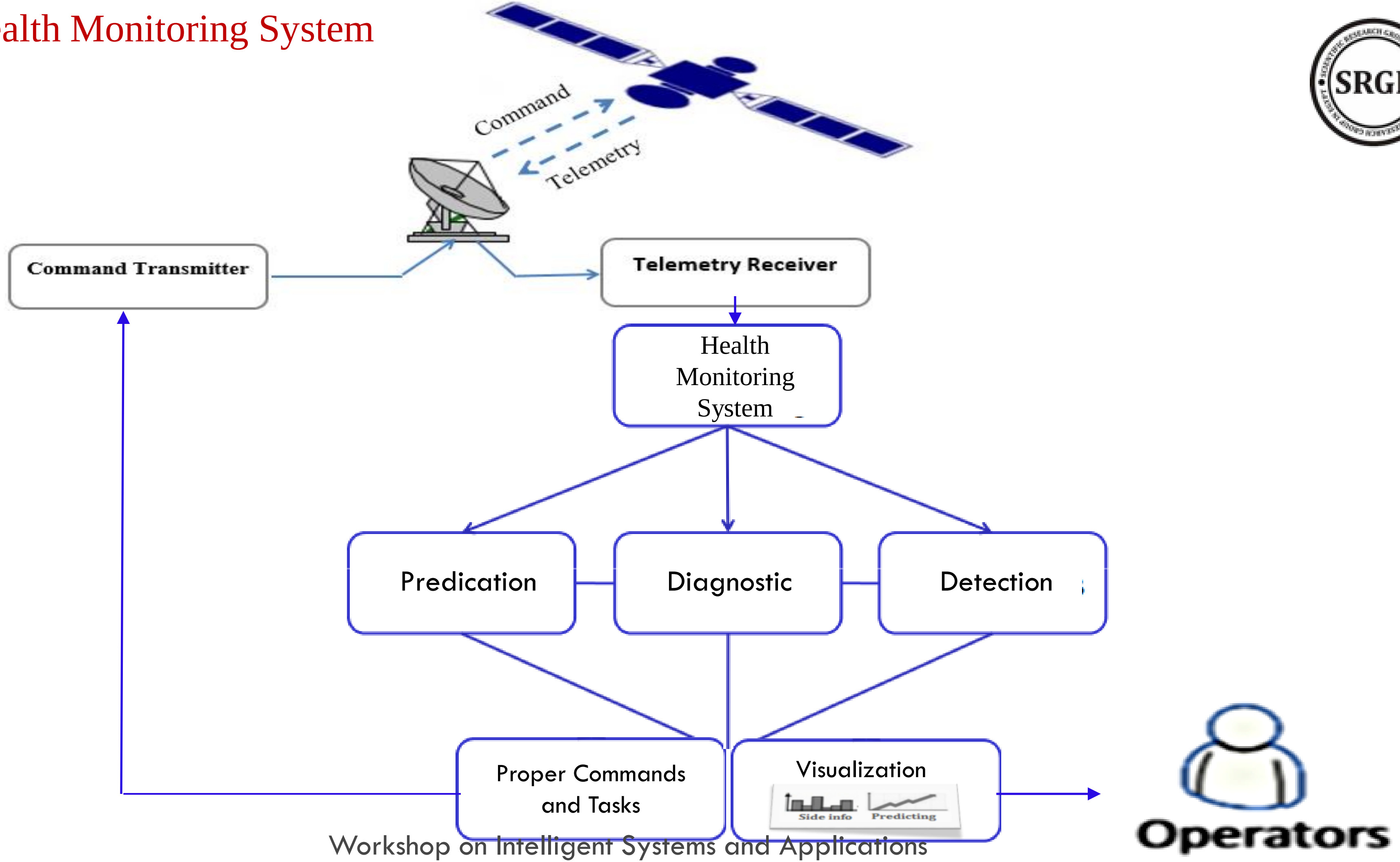


Telemetry Subsystem Block Diagram

Health Monitoring for Space Mission Operations

Health monitoring is essential to ensure that a satellite is operating properly and has no anomalies that could threaten its mission. It is monitored by analyzing the stream of Telemetry data received at the satellite ground control station. This data is received continually during the entire mission life of the Satellite. Hence a huge volume of data is collected for any given satellite. Data Mining and machine learning techniques are now regularly applied to examine archived/realtime spacecraft telemetry data and extract embedded information to produce advanced system health monitoring applications.

Health Monitoring System



Artificial Intelligence Approaches for Satellite Health Monitoring

Early Detection

Is to acquire the system behavior models necessary for anomaly detection from past data automatically

Remaining Useful Life (RUL) Estimation

It is the science of determining the remaining useful life of a component or subsystem given the current degree of wear or damage, the component's load history, and anticipated load and environmental conditions.

Numerical Simulation

Numerical simulation methods are proposed to simulate accurately subsystem performance under the lifecycle conditions like environmental hazards and dependent actions, which are important features that must be considered during satellite design, construction, and safety assessment

Rule induction and Association Rule Mining

for extracting hidden knowledge and relationships between apparently unrelated Telemetry parameters

Failure detection and Recovery

Detect and predict the telemetry readings of failed sensors by using historical data.

Fault Diagnostic and Prognostic

Analysis and timely predication of faults through using real-time and historical state information of subsystems can lead to appropriate action to be scheduled proactively to avoid catastrophic failures.

Risk and Reliability Assessment

It is a logical analysis method
Aims for identifying and assessing risk and reliability in systems for the purpose of improving safety and Performance based on some features, such as the spare components, the dependent failures, common cause failure and the failure recoveries.

Failure Detection and Recovery

- As the satellite fulfils their mission in a very special, harsh, and unpredictable environment, sensors are possible to fail or return unexpected response. Therefore, the failure detection and loss recovery are important issue to monitor and control the health of the satellite.

- Our proposed method introduces a new hybrid model for the failure detection and loss recovery based on support vector machine (SVM) and grey wolf optimization (GWO) algorithms. This new model uses SVM for performing failure detection and then predicting the telemetry readings values of the detected failed sensor by using historical data and correlated relations, and then comes GWO role for improving the predication and recovering accuracy. The hybrid GWO-SVM model was implemented on a satellite telemetry data and achieved very good results in term of recovering accuracy.

The Experimental Results

The function of the CubeSat telemetry subsystem like the generic case of any space system that is used to monitor various spacecraft parameters such as voltage, temperature, environmental readings and equipment status, and to transmit the measured values to ground. The telemetry packets have been used for the implementation in this study that are gathered from more than 30 sensors on the CubeSat, provide information about temperature, voltages and currents, appeared in the following parameters, as shown in the table

TABLE I

PARAMETERS OF CUBESAT TELEMETRY DATASET

Electrical Power Subsystem	Solar Panel Voltage X, Y, Z
	Battery Voltage
	Battery Temperature C
	Total Photo Current
	Boost Converter Temperature
	Total System Current
Sensor Subsystem	Sun Sensor X, Y, Z
	Solar Panel Temperature
	Bus Voltage
Communication Subsystem	Receive Current
	Transmit Current
RF Power Amplifier	RF Current Bus
	Device Temperature
Antenna Subsystem	Antenna Temperature

The Experimental Results

In the implementation, we firstly used SVM to detect the failure then evaluated the effectiveness of the GWO-SVM for predicting the missed values of failed sensor, we used three kernel methods of SVM, linear, quadratic and cubic. The table lists the detailed results obtained by different SVM kernel methods with 10 telemetry packet taken sequentially have one failed sensor, from the table we can see that all SVM kernel methods have achieved excellent prediction accuracy for the first two packets then the accuracy for the other packets began to decrease over the time.

Proposed Model	SVM Kernel Functions	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Average
GWO-SVM	Linear	99.96	99.71	95.1	97.58	94.28	96.1	90.5	94.88	81.1	62.65	91.186
	Quadratic	99.97	99.8	95.1	96.28	90.9	96	90.6	94	81.1	58.2	90.195
	Cubic	99.97	99.8	96.02	96.5	91	96.5	89.5	94.79	81.1	60	90.518

Thanks and Acknowledgement

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