NIAC Fellow Meeting

Architecture of Future Intelligent Earth Observing Satellites
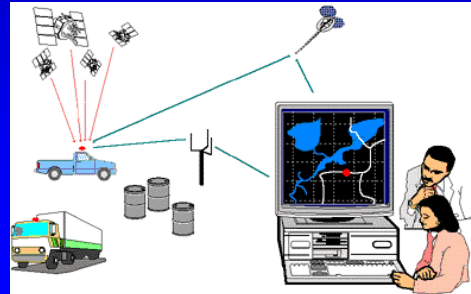
Dr. Guoqing Zhou
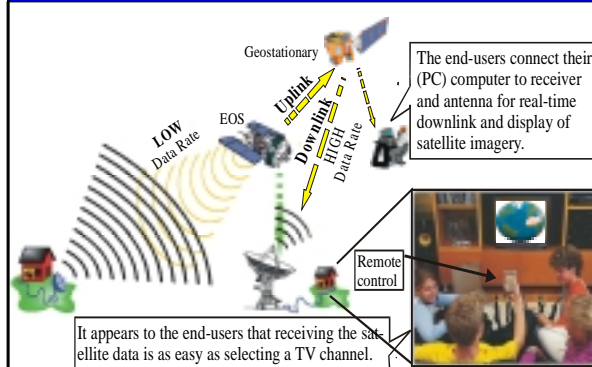
Old Dominion University

October 2001

To get your satellite information at anytime anywhere in the world…

Quickly, Inexpensively, Reliably

Receiving satellite images is as easily as selecting TV channel….

Geostationary

The end-users connect their (PC) computer to receiver and antenna for real-time downlink and display of satellite imagery.

EOS

LOW Data Rate

Uplink

Downlink

HIGH Data Rate

Remote control

It appears to the end-users that receiving the satellite data is as easy as selecting a TV channel.

I. Why Did We Propose This "Intelligent" System?

The 1ˢᵗ Generation: Operational Reconnaissance

(Early 1960s - 1972)

- CORONA, ARGON and LANYARD were the first three operational imaging satellite reconnaissance system launched in the early 1960's

GSD (m)	140	Swath (km)	556 x 556
Imaging mode	Frame Film	Inclination	82.3°
Band	Panchromatic	Stereo	Yes (70%)
Flying Height	322 km	Focus length	3 inch

ARGON 9034A mission, launched on May, 1962, Camera: KH-5

The 2ⁿᵈ Generation: Experimental Period and Initial Application

(1972 - 1986)

The Landsat 1, launched on August 7, 1972, symbolized the modern era of earth remote sensing.

- Multiple spectral bands
- High spatial resolution (80m)
- Large area (185km by 185km)
- Repeating coverage (every 18 days)
- Satellite image data directly in digital form for the first time
- Much of the foundation of multi spectral data processing in the early 1970s by NASA, JPL, USGS, ERIM, and LARS

Since 1972, Landsat TM in 1982, 1984 with 30m GSD and 7 spectral bands, until the SPOT HRV in 1986 with 10 m at Pan. band and 30 m GSD in 3 spectral bands

The 3ⁿᵈ Generation: Wide Application and Technique Further Developed

(1986 –1997)

1. **Linear array push-broom imaging mode:** SPOT
2. **Stereo mapping capability:** Off-nadir viewing stereoscopic imagery, SPOT
4. **Best GSD:** 10 m in panchromatic channel, SPOT
5. **Active microwave sensor:** radar imagery, ERS-1, ESA, 1991
6. **Multimission platform:** SPOT, PFM (Platform Multimission)
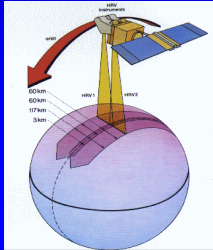
The 4ᵗʰ Generation: High-Resolution and Hyperspectral Satellites

(1997 - ?)

In 1995, a conference titled **"Land Earth Satellite for Decade"** sponsored by ASPRS, and co-sponsored by the Landsat Management Team (NASA, NOAA, and USGS), NIMA, USDA, EPA, NASA Applications, and others was held on September 1995 at Tyson's Corner, Virginia.

More than 700 experts from satellite companies, value-added producers and end user communities to study anticipated applications, detect potential problems, and discuss common solutions.

The result of this groundbreaking conference was that many participants thought that

The new generation is

High-Resolution, Multi(hyper)spectral Satellite

Owner	Name	Best GSD (m)	Launch Date
Earth Watch	Early Bird	3	12/24/1997
Earth Watch	QuickBird-2	0.61	10/18/2001
	QuickBird-1		Failed
SpaceImaging	Ikonos-2	1	9/24/1999
	Ikonos-1		Failed
ORBIMAGE	OrbView-3	1	End of 2001
	OrbView-4		Failed
USA Navy	NEMO	5	Late of 2001
USA/Israel	EROS A1	1.5	12/5/2000
USA/Isreal	EROS B1/B2	0.8	2003

Owner	Name	Best GSD (m)	Launch Date
India	IRS-P5 (Cartosat-1)	2.5	2002
India	IRS-2A (Cartosat-2)	1	2003
Germany	TerraSAR	1m Radar	2004
France	SPOT-5	5	2001
Canada	Radarsat-2	3m Radar	2003
Japan	ALOS	2.5	2003
China/Brasil	CBERS-3	3	2002
China/Brasil	CBERS-4	3	2003

History of Earth Observing Satellites
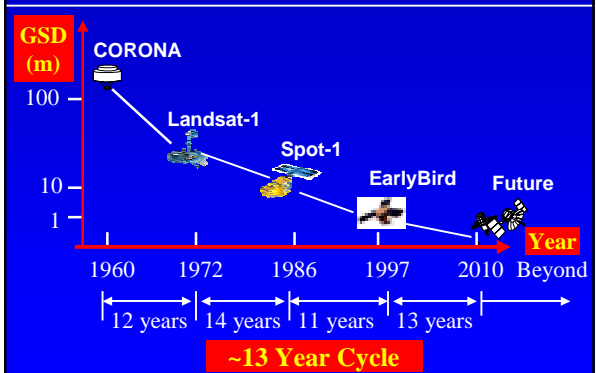
## II. What Is the NEXT "New Generation" of Earth Observing Satellite Beyond 2010?!

The Earth observation satellite has passed the **threshold** into maturity as a commercial space **activity**.
The major features of interest have moved from

| Imaging mode (sensors) | On-board data processor |

- Imaging mode (sensors)
- Spatial resolution
- Spectral resolution
- Spectral coverage
- Stereo capability
- Revisit capability
- Width of swath
- Orbital altitude

TO

- On-board data processor
- Event-driven data coll.
- Multi-angle viewing
- High spatial/temporal resolution
- HS land imaging
- Multi-sensors/satellites
- Value–added product

Architecture of Future Intelligent Earth Observing Satellites

---

Elements of Future Earth Satellites
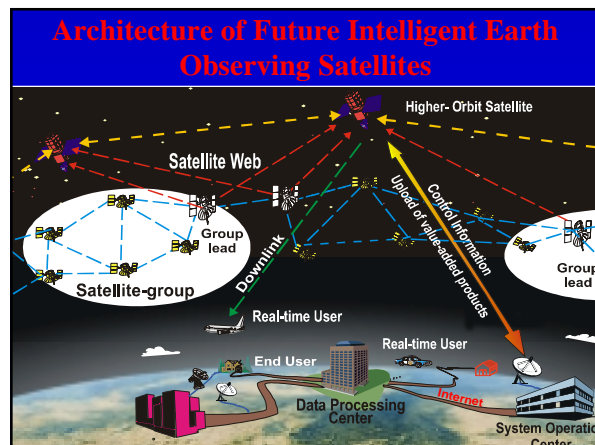
III. Concept Design of Future Intelligent Earth Observing Satellites

---

Design Principle

1. Usually, in space system design, one starts to define and specify the satellite system.

2. In contrast, the users and their needs form the starting point.

User's Requirements

New societal needs for information, especially mobile GIS and real-time GIS, have migrated from basic imagery to

- Temporal, dynamic imagery, e.g., flood disaster
- Specific site, e.g., World Trade Center disaster site
- Update frequently on hourly to minutes basis, analogous to today's weather updates
- Value-added products, e.g., geo-registration, feature enhancement, radiometric intensification, DTM, orthophoto, image mosaic, fused MS and Pan scene, etc.

Some Examples:

A mobile user: e.g., search-and-rescue pilot in an airplane

A real-time user: e.g. mobile GIS user, a portable receiver, small antenna and laptop computer

A common user: e.g., farmer, at a frequency of 1-3 days

A mineralogist: only hyperspectral imagery for distinguishing different metals

A cartographic user: e.g., photogrammetrist, panchromatic image

1. Concept Design for the End-User

Elements of End Users

- **Antenna and Receiver of "Intelligent" Satellite**
- **Communication between various users and Ground Control Station**
- **User Software for "Intelligent" Satellite Data Processing**

Antenna and Receiver of "Intelligent" Satellite:

- Hand-held antenna and receiver for real-time and mobile users
- Mobile antenna for mobile users
- Fixed antenna for popular users, professional users or satellite receiving station

Communication Between Various Users and Ground Control Station

Principle: Different users will need different imagery, and different imagery will be assigned different broadcast frequency.

The ground control station should

- Assigns various users with various receiving frequencies after payment.
- Communicate real-time with end-users for guidance about receiving frequencies, software use, display, etc.

User Software for "Intelligent" Satellite Data Processing

- Directly downloaded satellite data ≠ satellite imagery

- TV antenna receives a signal, not direct picture and sound. The signal must be transformed by TV set into picture and sound.

Similarly, the "imagery" is a type of *special signal*, which is only transformed by software which is provided by the ground control center so that real-time and common users can easily use it.

---

2. Concept Design of Space Segment

Elements of Space Segment

- **Multi-layer Satellites Networks**

- **On-Board Data Processing**

- **High-Speed Data Transmission (Crosslink, uplink and downlink)**

Multi-Layer Satellite Network

Earth observing satellites (EOSs) Network
- Hundred satellites with a different sensor
- Low orbits
- Satellite groups, group-lead.
  - Management of the member-satellites
  - Communication with other group-leaders
  - Communication with the geostationary satellites
- Member-satellites
  - Collection of data
  - Data processing on-board
  - Etc.
- On-board data processor, act autonomously

Geostationary Satellites Network
- Not all EOSs are in view
- Communication with end-users
- Communication with ground control stations
- Further processing of data

Network of An Organic Measurement System
- High speed optical and radio frequency links
- Archive facilities on the ground and on the satellite
- Group-leads (cross-link, uplink, and downlink)
- Member satellite (cross-links, uplink)

Concept Design for Multi-Sensor/Satellites

This system is specifically designed and built by support of multiple satellites and sensors
- current leading commercial
- being developed
- Future intelligent, e.g., neural network, smart, etc.
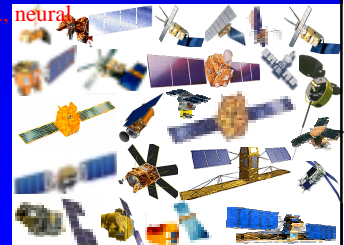
High-Speed Data Cross/up/down-links
(Group-lead/EOs ⟷ Geostationary)

❑ All group-lead satellite and EOs must establish and maintain a high-speed data cross-link

❑ All group lead satellite maintain uplinking with the geostationary satellites.

❑ All geostationary satellite must maintain dowlinking with users and ground data processing center.

High-Speed Data Cross/up/down-links
(Group-lead/EOs ⟷ Geostationary)

- Handheld wireless devices access satellite data for direct downlink
- The intelligent homes monitor their own internal environments by linking to atmospheric satellite data
- The intelligent satellites respond to environmental changes without human intervention.
- Satellite not only "see" user's environment, but also shape user's physical surroundings.

Concept Design for A Type of Imaging System
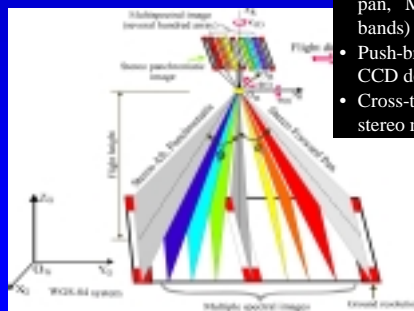
- Simultaneously collect pan, MS, and HS (200 bands) data
- Push-broom linear array CCD detectors
- Cross-track and in-track stereo mapping capability

3. Concept Design of Ground Segment

Elements of Ground Segment

1. **System Operation Center (SOC)**
   – Operations center (NOC)
   – Satellite management center (SMC)
2. **Data Processing and Distribution (DPD)**
   – Data Processing and Analysis Center (DPAC)
   – Data Distribution/Network Operation Center (DDC)
3. **End-User**

System Operation Center (SOC): Control Station

- Steers and monitors the satellite transmissions continuously
- Predicts the satellite ephemeris
- Calibrates the satellite flying parameters and the navigation message periodically
- Evaluates the satellite's performance (health and status)
- Take corrective measures when necessary

Network Operation Center (NOC)

- Communicates with the payload and end-users to support user access

- Establishes network connections

- Provides overall network management

- Communicates with end-users for problem solution, such as receiving frequency, channel, software, technical guides, etc.

- Provides science data filing, notification of scientists, and data distribution
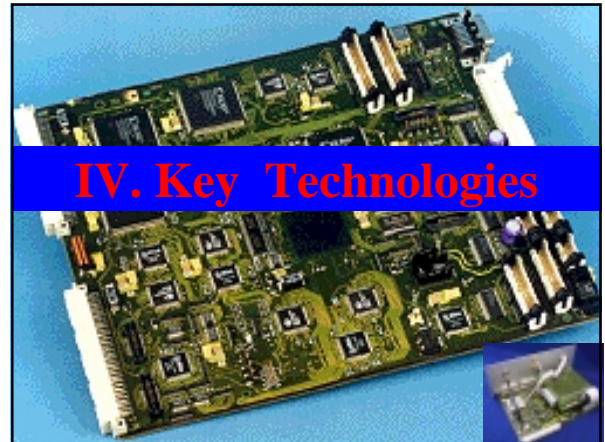
IV. Key Technologies

The proposed configuration of FIEOS is technically feasible. Clearly, information technology and real-time information systems which tie the satellite-network together and provide a degree of access to space-based instrument data currently does **NOT** exist.

- ❑ Data collection technologies
- ❑ High speed digital processors
- ❑ Optical and RF data links
- ❑ Network protocols
- ❑ Storage technologies

The Eyes in Space

Data Collection Technologies

- **Physical (Electromag.) Sensors:** temperature, atmospheric gases, water vapour, wind, waves, currents, and land use
- **Biological Sensors:** freshwater, toxic chemicals and pollutants, both in waters and in soils
- **Chemical Sensors:** atmospheric particles, their size and chemistry, transport, dispersion and deposition of heavy metals
- **Neural Network Sensor:** automatic target recognition, If a sensor saw mostly trees and one small, man-made structure, the pixel showed only trees

---

On-Board Data Processing Capabilities

- Data processor technology
- Image (signal) processor technology
- Software systems and algorithms
- High performance processing architectures
- Reconfigurable computing environments
- Generation of data products for direct distribution to users

One of the essential capabilities provided by on board processing is autonomy

---

Intelligent Platform Control

1. Platforms controlled intelligently and autonomously

2. Platforms adjust their positions in space relative to the constellation of sensors in response to collaborative data gathering

3. To operate autonomously single satellite and satellite-web

4. Decision support, planning

5. High level command protocols based on science objectives.

Network for High Data Rate Transmission

A high speed wireless (optical or RF) data linking to connect satellite to satellite, or satellite to ground is required.

The Weakest Links: the free space wireless cross-link of satellites and between satellite and ground.

The Greatest Challenge: establishment and maintenance of a viable communication network among a constellation of satellites operating in diverse orbits.

This is **NOT** a simple problem due to the relative velocities of the component satellites in the constellation.

Data Storage and Distribution

Many advanced and novel technologies

- Data mining

- Intelligent agent applications for tracking data, distributed heterogeneous frameworks (including open system interfaces and protocols)

- Data and/or metadata structures to support autonomous data handling
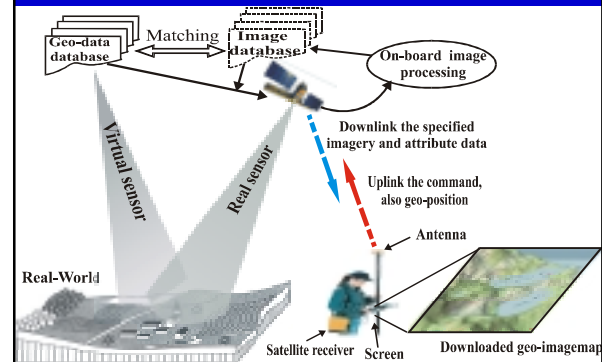
Value-Added Data Production

In order to make the value-added data products useful to a common user,

- Application software
- Application algorithms
- Dynamic searching
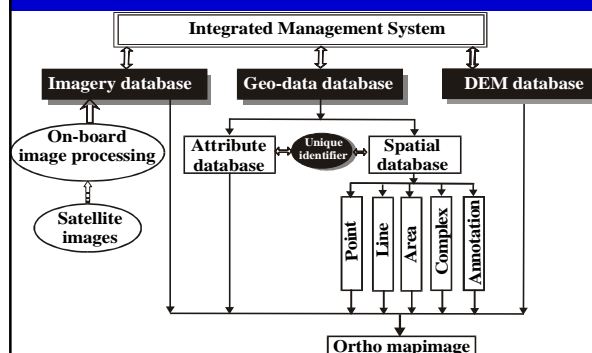- Dynamic collection and cataloging

Problems:

Computational Speed of Dynamic Interaction !!!!!

Prerequisite Condition of Direct Downlink

Integrated On-board Management System (Image, DEM and Geo-data)

V. Current Development

Naval EarthMap Observer (NEMO)

- **Automated, on-board processing, analysis, and feature extraction using the Naval Research Laboratory's (NRL's) Optical Real-Time Adaptive Signature Identification System (ORASIS)**
  - Realtime feature extraction and classification with greater than 10x data reduction
  - High-performance Imagery On-Board Processor provides greater than 2.5 gigaFLOPS of sustained computational power
  - On-board data storage (56 gigabit)

- **Military Application:** **Real-time tactical downlink of hyperspectral and products directly to the field for warfighter**
  - High data rate X-Band Downlink (150 Mbps)
  - Low data rate S-Band Tactical Downlink (1 Mbps)
  - Commercial satellite bus (Space Systems Loral LS-400)
 - Preconfigured Interface (PCI) for secondary payloads/experiments

**NEMO**
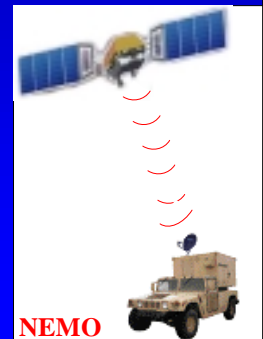
DLR BIRD Mission (Fire Monitoring)

- **On-Board Data Processing Capabilities**
  - A thematic on-board classificator for disaster warning and monitoring
  - Radiometric and geometric on-board correction of sensor signals
  - Geometric on-board correction of systematic alignment errors
  - Geometric on-board correction of spacecraft attitude
  - On-board geocoding of thematically processed data
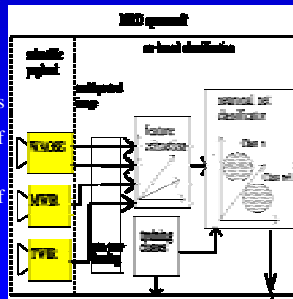
- **Real-time Downlink**
  - Immediate downlink of regional data
  - Downlink of an alert message if required
  - Store-and-forward, data downlink to low-cost payload ground stations
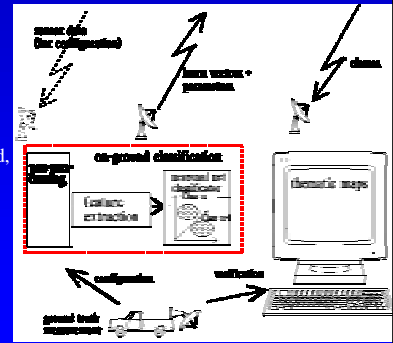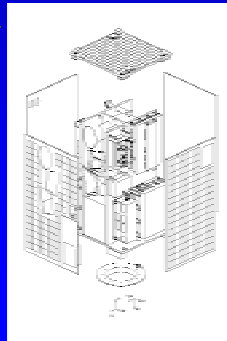

PROBA: ESA's Autonomy And Technology Demonstration Mission

Proba is an ESA mission conceived for the purpose of demonstrating new on board technologies and the opportunities and benefits of on-board autonomy.

- GPS receiver
- Autonomous star tracker
- A high-performance computer
- A Digital Signal Processor for on-board data processing and analysis
- A mass memory

MISSION OPERATIONS CONCEPT of PROBA

- **On-board housekeeping**
  - decision-making process, i.e. failure detection, failure identification and first-level recovery actions.
- **On-board data management:**
  - data handling, storage, and downlinks (a 1 Gbit mass memory for recording, a tuneable 2 Kbit/s to 1 Mbit/s down-link).

MISSION OPERATIONS CONCEPT of PROBA

- **On-board resources usage**
  - power and energy usages
- **On-board instrument commanding**
  - Planning, scheduling, resource management, navigation, and instrument pointing
  - Downlinks of the processed data
- **On-board science data distribution**
  - Automatic direct data distribution to different user without human involvement
  - Minimum possible delay

COCONUDS (Co-ordinated Constellation of User Defined Satellites)

coconuds

The objective is to ascertain the practicality of a radically different, low-cost, distributed network approach to satellite earth observation.

- Co-ordinated constellation of 10 polar orbiting micro-satellites
- Generating low-bitrate continuous data stream without on-board storage
- Four-band imagers, with 33 m resolution, and swath width of 350 km

---

- Distributed and free user community
- Ground stations are operated by end-users
- Minimum station configuration (3.5 Mbps)
- Higher performance stations (typical 100 Mbps)
- Area of interest from 2000 km radius with 2.5 m tracking dish to 400 x 400 km with fixed antenna
- For some point & shoot sensors users may uplink pointing requests

European Union
(Geosys, NRI, SSSL, and NLR)

VI. Financial, Political, Social and Institutional Issues

Really big bucks, literally billions, are required

- Investment from users, public and private sector

- Government agencies always have the highest priority
- In fact, some of government agencies are partially on the path toward construction

£

VII. Conclusion

❑ Focus on

The design of future earth observing satellites
  – Space segment
  – End-users segment
  – Ground segment.

❑ The key to this vision: Real-Time Info. System
  – On-board processing
  – Intelligent sensor control
  – High data rate transmission and network control
  – Intelligent platform control
  – Information production, distribution and storage

❑ Goal

To raise awareness as to
  – Needs
  – Possibilities
  – Benefits
  – Issues
  – Funding

❑ Future

1. Further assess key issues for such a advanced system

2. Raise awareness concerning:
    – autonomy domains and requirements for future space missions
    – currently available mature technology
    – verification and validation techniques for such a system
    – current state of the art and (in-flight) autonomy demonstrations in Europe and the United states

3. Stimulate co-operation between the Space and Research Communities and small businesses to solve critical problems of fielding advanced concepts in space

ACKNOWLEDGEMENTS

This project is funded by NASA Institute of Advanced Concept (NIAC). Our warmest thanks go to all the people who were kind enough to lend us their ears (or mail) to discuss a number of topics crucial for completion of our work.

Thank You

For More Information

gzhou@odu.edu