The Regional Center for Space Science and Technology Education for Western Asia (RCSSTE-WA)

The Regional Centre for Space Science and Technology Education in Asia and the Pacific (RCSSTEAP)- (China)

Intensive Curriculum on Global Navigation Satellite Systems (GNSS) & Remote Sensing (RS) & Geographic Information Systems (GIS)

Curriculum discerption:

Curriculum duration: 3 months

- 1 month GNSS
- 1 month RS
- 1 month GIS

Curriculum timing: 3 days a week, 2 lectures by 50 each.

1. Global Navigation Satellite Systems (GNSS)

1. Introduction

Global Navigation Satellite Systems (GNSS) include constellations of Earth-orbiting satellites that broadcast their locations in space and time, of networks of ground control stations, and of receivers that calculate ground positions by trilateration. GNSS are used in all forms of transportation: space stations, aviation, maritime, rail, road and mass transit.
Positioning, navigation and timing play a critical role in telecommunications, land surveying, law enforcement, emergency response, precision agriculture, mining, finance, scientific research and so on. They are used to control computer networks, air traffic, power grids and more. Thus the specific objectives of the implementation of the GNSS education curriculum are the demonstration and understanding of GNSS signals, codes, biases and practical applications, and the implications of prospective modernization.

At present GNSS include many fully operational global systems, the United States' Global Positioning System (GPS), China's COMPASS/Bei-Dou, the Russian Federation's Global Navigation Satellite System (GLONASS), Europe's European Satellite Navigation System (GALILEO) and India's Regional Navigation Satellite System (IRNSS) and Japan's Quasi-Zenith Satellite System (QZSS). Once all these global and regional systems become fully operational, the user will have access to positioning, navigation and timing signals from more than 100 satellites.

Globally there is growing interest in better understanding solar-terrestrial interactions, particularly patterns and trends in space weather. This is not only for scientific reasons, but also because the reliable operation of ground-based and space-based assets and infrastructures is increasingly dependent on their robustness against the detrimental effects of space weather. GNSS now is an essential part of space technology applications for remote sensing, precision agriculture, aviation, transport and communications, and e-learning.

All aspects of the agriculture industry, from basic rural cadaster and surveying to advanced precision agriculture, benefit from the use of GNSS. Agro-climatic and ecological-economic zonings, crop inventory, monitoring and forecasting are examples of agricultural activities where positioning and timing are of paramount importance. In the area of climate change, different factors and mechanisms drive land use and transformation. In many cases, climate, technology and economics appear to be determinants of land use. At the same time, land conversion is an adaptive feedback mechanism that farmers use to smooth the impact of climate variability, especially during extremely wet or dry periods.

Satellites are an indispensable resource for monitoring and observing the Earth and its weather systems. They gather data for global climate models, and efforts continue in developing refined models that can be used in regional and national settings. The use of GNSS has been significant in making detailed observations of key meteorological parameters, whose measurement stability, consistency and accuracy could make it possible to quantify long-term climate change trends.

In the area of transport, studies have shown that civil aviation will significantly benefit from the use of GNSS. These benefits include improved navigation coverage in areas currently lacking conventional tracking aids, accurate and reliable information about aircraft positions and routes that enables safe and efficient management of air traffic, (particularly on airport approaches). Road transport applications can automatically revise a route to account for traffic congestion, changes in weather conditions or road works. Similarly, at sea, GNSS technologies can provide efficient route planning, collision avoidance and increased efficiency in search and rescue situations. For rail transport, GNSS offers enhanced cargo monitoring and assists track surveying. In addition, communication systems, electrical power grids and financial networks all rely on precision timing for synchronization and operational efficiency. For example, wireless telephone and data networks use GPS time to keep all of their base stations in perfect synchronization. This allows mobile handsets to share limited radio spectrum more efficiently.

Critical applications, such as railway control, highway traffic management, precision agriculture, emergency response, commercial aviation and marine navigation, require and depend on GNSS services. Everyday activities, such as banking, mobile phone operations and even the control of power grids, are facilitated by the accurate timing provided by GNSS. As national, regional and international infrastructure and economy are increasingly dependent on positioning, navigation and timing services, society at large is vulnerable to disruptions that can be caused by space weather or variable conditions on the Sun and in the space environment that can influence space-borne and ground-based technological systems. Just as society takes for granted that electricity, heat and clean water will be available, it also takes for granted that GNSS will be available, reliable and accurate. GNSS is so entrenched in the daily activities of individuals, businesses and government that any loss of satellite positioning, navigation and timing services would be widely disruptive.

This course should result in helping the development and growth of capacities that will enable to enhance its knowledge, understanding and practical experience in those aspects of space science and technology that have the potential for a greater impact on its economic and social development, including the preservation of its environment. The GNSS education curriculum was developed by taking into account GNSS course outlines as used at the university level in a number of developing and industrialized countries. The incorporation of elements of GNSS science and technology into university-level education curricula served a dual purpose: *(a)* it could enable countries to take advantage of the benefits inherent in the new technologies, which, in many cases, are spin-offs from space science and technology; or *(b)* to introduce the concepts of high technology in a non-esoteric fashion and help create national capacities in science and technology in general. Currently serious efforts are being made worldwide to introduce GNSS, in terms of science, technology and applications, as a stand-alone discipline in university-level curricula.

2. Curriculum on global navigation satellite systems

The course consists of nine modules covering specific areas of GNSS (theory, technology and applications). The duration of the course is 4 weeks. The courses take place 3 days a week, with two 50-minute sessions per day.

Module	Topic	Duration in hours
	Lectures	**24**
I:	Fundamentals	2
II:	Position determination techniques	2
III:	Technologies: augmented systems	4
IV:	Sensors and embedded system design	2
V:	Receivers	4
VI:	GNSS/INS integrated navigation	4
VII.	GNSS applications	4
VIII.	Space weather and GNSS	2

The breakdown by module and type of course are as follows:

Module I. Fundamentals

1.1 Introduction to GNSS: *Conventional navigation, background, concepts and evolutions of global navigation satellite systems (GPS, GLONASS, Galileo, BeiDou/ COMPASS) and regional navigations satellite systems (IRNSS, QZSS). Comparison of GNSS with other navigation systems;*

1.2 Reference systems: *Terrestrial, celestial and orbit coordinate reference system. Height Systems. Geoid. Time systems, synchronization and data conversion. Transformations* *between coordinate reference systems. Contribution of the International GNSS Service (IGS) to providing access to the International Terrestrial Reference Frame (ITRF);*

1.3 Satellite orbits: *Orbital parameters. Orbital motion, representation (Keplerian elements, etc) Determination of satellite position, visibility and ground tracks;*

1.4 Basic techniques of communications: *Propagation of electromagnetic waves. Antennas and propagation channels. Signal modulation and multiple accesses. Signal processing.*

1.5 Current Main Navigation Systems

1.5.1 GPS Modernization Program

1.5.2 Russian GLONASS System

1.5.3 Chinese BeiDou System

1.5.4 GALILEO Satellite System

1.5.5 Augmentations

1.6 Application of Navigation Technology

Module II. Position determination techniques

2.1 GNSS measurements: pseudo-ranges, carrier phase and Doppler;

2.2 Position determination techniques (general);

2.3 Single point position technique: models and estimation methods;

2.4 Satellite constellation and dilution of precision: satellite geometry, bounds and calculations on dilution of precision (DOP).

Module III. Technologies: augmented systems

3.1 Errors in GNSS measurements: functional model and fundamental error equation, effect of GDOP, classes of ranging errors and biases;

3.2 Effects of errors: error budget, user equivalent range error, position accuracy with one sigma and three sigma errors;

3.3 Error mitigation techniques: real time kinematic (RTK), differential GNSS (DGGNSS), local area DGNSS, wide area DGNSS;

3.4 Augmented systems: Wide Area Augmentation System (WAAS), European Geostationary Navigation Overlay Service (EGNOS), System of Differential Correction and Monitoring (SDCM), Multi-functional Transport Satellite (MTSAT) Satellitebased Augmentation System (MSAS), GPS Aided Geo Augmented Navigation (GAGAN), etc.;

3.5 GNSS networks: Global, regional and local GNSS Permanent Networks and geodetic infrastructure for real positioning services;

3.6 GNSS impact factors and mitigation techniques: Orbit errors, clock errors, multipath, troposphere, ionosphere including higher order ionospheric refraction effects, vulnerability against space weather, jamming.

Module IV. Sensors and embedded system design

4.1 Sensors and transducers: Introduction, Sensor classification, characteristics and compensation, classification of transducers. Transducer descriptions, parameters, definitions and terminology;

4.2 Embedded systems: Cell phones, pagers, PDAs, answering machines, microwave ovens, televisions, VCRs, CD/DVD players, video game consoles, GNSS devices, network routers, fax machines, cameras, music synthesizers, planes, spacecraft, boats, and cars all contain embedded processors.

Module V. GNSS receivers

5.1 Receiver architecture: Technology, radio-frequency front end, signal processing system hardware and software techniques, software defined radio;

5.2 Signal tracking: Maximum likelihood estimate of delay and position, delay lock tracking of signal, coherent and non-coherent delay lock tracking of pseudo noise sequences, mean square error estimation, vector delay lock loop, receiver noise performance, maximum likelihood estimate, early late gating;

5.3 Navigation algorithm: Measurement of pseudo range, Doppler, decoding and usingof navigation data, single point solution, precise point positioning, dynamics of user, Kalman filter, least-squares adjustment, and other alternatives.

Module VI. GNSS/INS integrated navigation

6.1. Inertial navigation systems. Accelerometer, Gyroscopes, Inertial platforms, Navigation equation, Integration of modelling equations in e-frame;

6.2. INS error dynamics: Simplified analysis, Error dynamics equations in e-frame, INS initialization and alignment;

6.3. GNSS/INS integration: Integration mode, Mathematical model of supported INS navigation, Observation procedures for inertial surveying;

6.4. General sensor fusion concepts.

Module VII. GNSS applications

7.1. Geospatial databases: Geo extensions for Open Source Databases, POSTGRES, MySQL etc.;

7.2. GNSS navigation: Professional and personal, GIS/mapping, Surveying, Natural Hazards management, Earth sciences, Natural resources, Infrastructure;

7.3. Navigation and communication: Integrated application;

7.4. Communication, navigation and surveillance: Integrated application;

7.5. GNSS applications for remote sensing of the atmosphere and space weather: Radio occultation technique for monitoring terrestrial weather (temperature and water vapour) and onitoring ionospheric weather (electron density and total electron content);
7.6. Revenue model for value added services;
7.7. Management, team work, intellectual property, business in GNSS.

Module VIII. Space weather and GNSS

8.1. Sources of space weather and related background physics: Sun, galactic cosmic rays, magnetosphere, thermosphere, ionosphere coupling;
8.2. Impact of space weather events on GNSS;
8.3. Satellites, interference with solar radio emission, radio wave propagation;
8.4. Different view in precise (geodesy, DGPS) and safety of life (aviation) applications;
8.5. Ionospheric scintillations and their impact, monitoring and modeling;
8.6. GNSS-based monitoring of the ionosphere by ground and space based measurements;
8.7. Ionospheric correction and threat models.

3. References

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M. Capderou. *Satellites, Orbits and Missions.* Springer Verlag France. Paris, France, 2005

K. Davis. *Ionospheric Radio,* Peter Peregrinus Ltd. London, United Kingdom, 1990

F. van Diggelen. *A-GPS, Assisted GPS, GNSS, and SBAS,* Artech House, Boston, London, 2009

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M. Hapgood, and A. Thomson. *Space weather: Its impact on Earth and implications for business.* Lloyd’s 360° Risk Insight. London, United Kingdom, 2010. Available at: http://bit.ly/9Pjk9R

B. Hofmann-Wellenhof, K. Legat, M. Wieser. *Principles of Positioning and Guidance.* Springer, Wien New York, 2003

B. Hofmann-Wellenhof, H. Lichtenegger, E. Wasle. *GNSS-Global Navigation Satellite Systems (GPS, Glonass, Galileo and more),* Springer, Wien, New York, 2008

P. Kuhnert and B. Venables. *An Introduction to R: Software for Statistical Modelling & Computing.* CSIRO Mathematical and Information Sciences. Cleveland, Australia, 2005

W. Mansfeld. *Satellitenortung und Navigation (Grundlagen, Wirkungsweise und Anwendung globaler Satellitennavigationssysteme)*, 3. Auflage, Praxis, Vieweg+Teubner, Berlin, 2010

B. W. Parkinson and J. J. Spilker, Jr (eds). (1996): *Global Positioning System: Theory and Applications (Vol. I.).* AIAA. Washington, DC.

R. Schunk and A. Nagy. *Ionospheres: Physics, Plasma Physics and Chemistry* (2nd ed.). Cambridge University Press. Cambridge, United Kingdom, 2009

R. H. Shumway, D. S. Stoffer. *Time Series Analysis and Its Applications (with R examples)* (3rd ed). Springer Verlag. New York, NY, 2011

W. Zucchini and O. Nenadić. *Time Series Analysis with R - Part I.* University of Goettingen, Germany, 2011. Available at: http://bit.ly/HsiVH

J-M. Zogg. *GPS: Essentials of navigation (Compedium)*. u-blox AG. Thalwill, Switzerland, 2010. Available at: http://bit.ly/fhT71T Available courses, including on GNSS and its applications:

ESA International Summer School on Global Navigation Satellite Systems: http://www.esa.int/esaNA/SEMQWXQVEAG_index_0.html

Galileo Information Center for Latin America: http://www.galileoic.org/

Global Positioning System, Serving the World: http://www.gps.gov/

Internet Courses on Global Navigation Satellite Systems: University of Maine, USA: http://www.gnss.umaine.edu

Master of Science (MSc) in Global Navigation Satellite Systems (GNSS): http://www.enac.fr/en/menu/training/master-science-degrees/master-gnss

NAVKIT educational tool: http://www.navsas.eu/

NavtechGPS: http://www.navtechgps.com

Research group of Astronomy and GEomatics (gAGE), Technical University of Catalonia (UPC), Barcelona, Spain: http://www.gage.es/

Regional centres for space science and technology education affiliated to the United Nations www.unoosa.org/oosa/en/SAP/centres /index.html

United Nations/Italy Long-term Fellowship Programme on GNSS and Related Applications, Master in Navigation and Related Applications (MNA): www.unoosa.org/oosa/SAP/gnss/fellowships.html

Remote sensing and the geographic information system

Preface

Thousands of years ago, on a small rocky planet orbiting a modest star in an ordinary spiral galaxy, our remote ancestors looked up and wondered about their place between Earth and sky. In the twenty-first century, people ask the same profound questions about how the universe began and evolved, how people got here, where they are going and whether they are alone in the universe. After only the blink of an eye in cosmic time, those questions are beginning to be answered. In the last 40 years, space probes and space observatories have played a central role in that process.

All life on Earth depends on the thin layer of gas that surrounds the globe; it is called the atmosphere, taken from the Greek word *atmos* (vapor) and the Latin word *sphaera* (sphere). Remote sensing of the atmosphere attempts to quantify numerous variables: cloud coverage and identity, water vapor concentration and precipitation rate, wind speeds, atmospheric aerosol and trace gas concentrations, and even lightning in storms.

The term atmosphere has led to the creation of several other words to describe various divisions of the Earth's environmental systems:

- The hydrosphere, encompassing oceans, rivers, lakes and snow and ice on both land and sea;
- The biosphere, referring to the living things that inhabit the Earth, which for remote-sensing purposes primarily means land vegetation and oceanic phytoplankton;
- The geosphere, covering such areas as the Earth's radiation budget, the physical topography of the continents, geological processes that modify the land surface, the dynamic activity of volcanoes and the movement of the Earth's continental plates;
- The anthroposphere, meaning the influence of humanity on the surface of the Earth through structures and activity that have the potential to significantly alter the Earth's climate.

The primary processes that remote sensing seeks to measure in each of these spheres and the technical aspects of remote-sensing observations for each of these systems in terms of educational modules are described in the present course.

The incorporation of elements of space science and technology into university- level science curricula can serve a dual purpose for developed and developing countries. It can enable all countries to take advantage of the benefits inherent in the new technologies, which, in many cases, are spin-offs from space science and technology. It can revitalize the educational system, introduce the concepts of high technology in a non-esoteric fashion and help create national capacities in science and technology in general.

There are many challenges in the teaching of science at university level, both in developing and developed countries, but the challenges are of a higher magnitude in developing countries. The general problem confronting science education is the inability of students to see or experience the phenomena being taught, which often leads to an inability to learn basic principles and to see the relationship between two or more concepts and their practical relevance to problems in real life. Added to those problems are a lack of skills in the relevant aspects of mathematics and in problem-solving strategies. There are also language problems in countries in which science is not taught in the national language.

The course general description:

This course aims to give students advanced theoretical information in remote sensing, and includes recent developments in remote sensing, electromagnetic radiation on the surface of the Earth (electromagnetic energy, electromagnetic spectrum, sources and types of electromagnetic energy used in remote sensing, and interactions of the Earth's surface (soil , Water, and plants) with the electromagnetic spectrum, microwave wave interactions with the Earth's surface, aerial imagery and space visuals, engineering correction, radiometric correction, visual image optimization, visual classification (observer classification, unattended classification), and classification accuracy calculation.

The course aims to get the participants familiar with the basic concepts of climate science and gain sufficient skills to positively deal with the prevailing climate conditions. It includes a study of the basic principles of the interrelationship between solar energy, climatic patterns, climate elements and factors affecting that geographical distribution of climatic regions. The student makes some measurements of climate elements and attempts to apply this to activities Various and writing reports.

Module/ submodule	*Topics*
0	Introduction An induction module for students on the culture, social, economic and developmental aspects of the host country and institutions, with brief lectures on overall general topics
1	Fundamentals and principles of remote sensing and GIS (2-3 months)
1.1	Principles of remote sensing
1.1.1	Overview of remote sensing technology: history and evolution
1.1.2	Electromagnetic radiation and its interaction with matter: Laws of radiation, electromagnetic spectrum and its characteristics, sources of electromagnetic

	radiation; propagation of electromagnetic energy: dispersion, scattering, absorption, refraction and reflection; interactions between electromagnetic radiation and matter in the atmosphere and on the Earth's surface (emission of radiation): emissivity, black body radiation, Stefan's law, Kirchoff's law, Wien's law, Planck's law; physical processes in the interaction of radiation and matter: properties of the atmosphere, constituents, contaminants, lapse rate, clouds, atmospheric sounding, scattering mechanisms, temporal variations; albedo, reflection, Snell's law, absorption, spectral signatures, photoelectric effect, insulation.
1.1.3	Spectral characteristics of crops/vegetation, soils, water etc.
1.2	Remote sensing platforms, sensors and ground systems
1.2.1	**Platforms** – General overview of airborne remote sensing: photography, imaging; advantages and applications – Satellite remote sensing: classification by orbit, applications, advantages and disadvantages, type of observation, orbital dynamics – Types of satellites: overview of Earth observation satellites; overview of optical infrared (IR) remote sensing sun-synchronous satellites; overview of polar platforms and meteorological satellites – High-resolution satellites; radar satellites; other missions: hyperspectral etc. – Future satellite systems
1.2.2	**Sensors** – Fundamentals of imaging technology: imaging/non-imaging, active/passive, advantages and disadvantages – Concept of resolution: spatial, spectral, radiometric and temporal – Aerial photography systems: photographic, historical, camera systems, film types, multispectral photography, airborne laser terrain mapper (ALTM) – Scanners/imagers: frame camera systems, scanning systems, pushbroom scanners, spectrometers, charge-coupled device (CCD), thermal imagers – Microwave sensors: principles of side-looking airborne radar (SLAR), synthetic aperture radar (SAR) and its characteristics – Non-imaging sensors/systems: infrared radiometer, microwave radiometer, scatterometer, altimeter etc. – Other sensors: hyperspectral, laser imaging etc.

1.2.3	Ground systems – Data reception and pre-processing systems and their configurations – Principles of data reception systems, data transmission and receive chains; recording; archival; pre-processing: radiometric and geometric corrections; types of satellite data products; value-added products – Ground data collection and verification; errors in image data and their correction
1.3	Image interpretation
1.3.1	Fundamentals of aerial photo interpretation
1.3.2	Principles of image interpretation of optical, thermal and microwave satellite data
1.4	Photogrammetry
1.4.1	Introduction to photogrammetry: aerial photography, photo interpretation, analogue photogrammetry, digital photogrammetry
1.4.2	Principles of accuracy assessment and error analysis
1.5	Digital image processing
1.5.1	Overview of programming languages: C++ (an object-oriented programming language), visual basic (VB), macro languages
1.5.2	Statistical concepts: average, median, mode, standard deviation, covariance matrix, eigenvalues, eigenvectors, principal component analysis etc.
1.5.3	Ground data for digital image processing
1.5.4	Elements of digital image processing and pre-processing: radiometric, geometric and atmospheric corrections
1.5.5	Image enhancement techniques: histograms, contrast stretching, transfer functions, histogram equalization, histogram specification
1.5.6	Filtering: low- and high-pass filters, ideal filter, Butterworth filter, exponential filter, trapezoidal filter etc., smoothing
1.5.7	Classification techniques: spectral distances, probabilities, error analysis, clustering, training areas, sampling methods, extrapolation; per-pixel classifier, Maximum likelihood (MXL)/Bayesian/ parallelepiped etc., classifiers, object-oriented classifier, Neural Networks (NN), textural, fractals.
1.5.8	Accuracy assessment and error analysis
1.5.9	Image fusion techniques
1.5.10	Image segmentation and feature extraction techniques: knowledge-based techniques, artificial intelligence, fuzzy image concepts
1.5.11	Image transforms and wavelets

1.5.12	Stereo image processing techniques
1.5.13	High-resolution image analysis techniques
1.5.14	Principles of analysis of SAR data, SAR interferometry and differential-interferometric synthetic aperture radar (INSAR) techniques
1.5.15	Processing hyper-spectral, polarimetric, ALTM and other types of data
1.6	Image processing systems
1.6.1	Configuration, choice and selection
1.6.2	Integrated image analysis and GIS
1.7	Geographic information system
1.7.1	Characteristics and types of GIS data: types of data; concept of information
1.7.2	Maps and projections: principles of cartography, ellipsoids, cartographic projections, coordinate systems, types and scales; accuracy of maps
1.7.3	GPS concepts, techniques, systems and applications
1.7.4	GIS principles: concepts and principles of GIS: GIS models, GIS components, inputs to GIS; GIS database design and organization; integration in GIS, querying in GIS, GIS outputs and visualization, accuracy of data in GIS, GIS integration errors
1.7.5	3-dimensional GIS: representing 3rd dimension in GIS, 3-dimensional analysis and derivatives
1.7.6	Concepts of temporal GIS, decision support systems, GIS modelling, visualization techniques, virtual reality, mobile mapping, World Wide Web-GIS
1.7.7	Illustrations and overview of GIS applications
1.7.8	Spatial data infrastructures: metadata, search/access, data warehousing, data mining, standards, specific programs of countries (United Nations Environment Program (UNEP)/Global Resource Information Database (GRID), digital Earth, global spatial data infrastructure (GSDI), global mapping etc.); common standards: open GIS, ISOTC211
2	Remote sensing applications
2.1	Overview of remote sensing and GIS applications (1 month; common module for all streams)
2.1.1	Remote sensing and GIS applications for water resources; agriculture; urban; coastal and oceans; environment; forestry; ecology; geology; mapping and others
2.1.2	Earth processes
2.1.3	Satellite meteorology
2.1.4	Natural disasters
2.1.5	Sustainable development and carrying capacity

2.1.6	Environmental analysis, monitoring and management
2.1.7	Cost-benefit analysis
2.1.8	Project planning and execution
2.2	Thematic streams
2.2.1	Review for project planning and execution for pilot project: Pilot project to be executed at the regional center; the topics are chosen by the student, in consultation with his/her sponsoring organization and approved by the center

Suggested reading

- American Society of Photogrammetry and Remote Sensing. Manual of remote sensing. v. I. and II. 2. ed. Falls Church, Virginia, 1983.
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