GNSS Remote Sensing

Remote Sensing and Digital Image Processing

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Theory, Methods and Applications

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Preface

The Global Navigation Satellite System (GNSS) has provided an unprecedented high accuracy, flexibility and tremendous contribution to navigation, positioning, timing and scientific questions related to precise positioning on Earth's surface, since Global Positioning System (GPS) became fully operational in 1994. Since GNSS is characterized as a highly precise, continuous, all-weather and near-real-time microwave (L-band) technique, additional more applications and potentials of GNSS are being explored by scientists and engineers. When the GNSS signal propagates through the Earth's atmosphere, it is delayed by the atmospheric refractivity. GNSS radio occultation together with ground GNSS have been used to produce accurate, all-weather, global refractive index, pressure, density profiles in the troposphere, temperature with up to the lower stratosphere (35–40 km), and the ionospheric total electron content (TEC) as well as electron density profiles, to improve weather analysis and forecasting, monitor climate change, and monitor ionospheric events. Therefore, GNSS has great potentials in atmospheric sounding, meteorology, climatology and space weather.

In addition, surface multi-path is one of main error sources for GNSS navigation and positioning. It has recently been recognized, however, that the special kind of GPS multi-path delay reflected from the Earth's surface, could be used to sense the Earth's surface environments. A recent interesting result on fluctuations in near surface soil moisture has been successfully retrieved from the ground GNSS multi-path, fairly matching soil moisture fluctuations in soil measured with conventional sensors. In addition, the space-borne GNSS received delay of the GNSS reflected signal with respect to the rough surface could provide information on the differential paths between direct and reflected signals. Together with information on the receiver antenna position and the medium, the delay measurements associated with the properties of the reflecting surface can be used to produce the surface roughness parameters and to determine surface characteristics. The Bistatic radar using L-band signals transmitted by GNSS can be as an ocean altimeter and scatterometer. A number of experiments and missions using GNSS reflected signals from the ocean and land surface have been tested and applied, such as determining ocean surface height, wind speed and wind direction of ocean surface, soil moisture, snow and ice thickness.

Therefore, the refracted, reflected and scattered GNSS signals can image the Earth's surface environments as a new, highly precise, continuous, all-weather and near-real-time remote sensing tool, which is expected to revolutionize various atmospheric sounding, ocean remote sensing and land/hydrology mapping, especially for various Earth's surfaces and the atmosphere. With the development of the next generation of multi-frequency and multi-system GNSS constellations, including the US's modernized GPS-IIF and planned GPS-III, Russia's restored GLONASS, and the coming European Union's GALILEO system and China's Beidou/COMPASS system as well as a number of Space Based Augmentation Systems, such as Japan's Quasi-Zenith Satellite System (QZSS) and India's Regional Navigation Satellite Systems (IRNSS), more applications and opportunities will be exploited and realized using new onboard GNSS receivers on future space-borne GNSS reflectometry and refractometry missions in the near future.

GNSS Remote Sensing –Theory, Methods and Applications has been written as a monograph and textbook that guides the reader through the theory and practice of GNSS remote sensing and applications in the atmosphere, oceans, land and hydrology. This book covers Chap. 1: Introduction to GNSS, Chap. 2: GNSS Atmospheric and Multipath Delays, Chap. 3: Ground GNSS Atmospheric Sensing, Chap. 4: Ground-Based GNSS Ionospheric Sounding, Chap. 5: Theory of GNSS Radio Occultation, Chap. 6: Atmospheric Sensing using GNSS RO, Chap. 7: Ionospheric Sounding using GNSS-RO, Chap. 8: Theory of GNSS Reflectometry, Chap. 9: Ocean Remote Sensing using GNSS-R, Chap. 10: Hydrology and Vegetation Remote Sensing, Chap. 11: Cryospheric Sensing using GNSS-R and Chap. 12: Summary and Future Chances. Chapters 1, 2, 3, 4, 7, 10, 11 and 12 were contributed from Prof. Shuanggen Jin, Chaps. 5 and 6 were contributed from Dr. Feiqin Xie, Chaps. 8 and 9 and part of Chap. 11 were contributed from Dr. Estel Cardellach as well as some contributions from Rui Jin and Xuerui Wu.

This book provides the theory, methods, and applications of GNSS Remote Sensing for scientists and users who have basic GNSS background and experiences. Furthermore, it is also useful for the increasing number of next generation multi-GNSS designers, engineers and users community. We would like to thank Assistant Editor's help and Springer-Verlag for their cordial collaboration and help during the process of publishing this book.

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Contents

Acronyms

ABL	Atmospheric Boundary Layer
AGW	Acoustic Gravity Wave
ART	Algebraic Reconstruction Technique
AMSR-E	Advanced Microwave Scanning Radiometer for Earth Observing System
AODC	Attitude and Orbit Determination and Control
BDS	Beidou Navigation System
BOC	Binary Offset Carrier
BPSK	Binary Phase Shift Keying
C/A	Coarse/Acquisition
CAS	Chinese Academy of Sciences
CDMA	Code Division Multiple Access
CHAMP	Challenging Mini-satellite Payload
COADS	Comprehensive Ocean-Atmosphere Data Set
CL	Close-loop
CMONC	Crustal Movement Observation Network of China
CODE	Center for Orbit Determination in Europe
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
CICERO	Climate Community Initiative for Continuing Earth Radio Occultation
CIT	Computerized Ionospheric Tomography
CYGNSS	CYclon GNSS
DCB	Differential Code Biases
DD	Double Difference
DDM	Delay-Doppler Map
DMC	Disaster Monitoring Constellation
DGPS	Differential GPS
DMC	Disaster Monitoring Constellation
DMSS	Directional Mean Square Slope
DNSS	Defense Navigation Satellite System

DOD	Department of Defense
DORIS	Doppler Orbitography Radio positioning Integrated by Satellite
DOT	Department of Transportation
ECMWF	European Centre for Medium-Range Weather Forecasts
EGNOS	European Geostationary Navigation Overlay Service
ESA	European Space Agency
EST	Equivalent Slab Thickness
EU	European Union
FFT	Fast Fourier Transform
FDMA	Frequency Division Multiple Access
FIO	Fourier Integral Operators
Galileo	Global Navigation Satellite System of EU
GAGAN	GPS Aided Geo Augmented Navigation
GAMIT	GPS analysis software by Massachusetts Institute of Technology
GBAS	Ground-Based Augmentation Systems
GDOP	Geometric Dilution of Precision
GEO	Geostationary Earth Orbit
GFZ	GeoForschungsZentrum Potsdam
GIPSY-OASIS	GNSS-Inferred Positioning System and Orbit Analysis
GLONASS	Global Navigation Satellite System of Russia
GMF	Global Mapping Function
GNSS	Global Navigation Satellite Systems
GO	Geometric Optics
GOLD-RTR	GPS Open-Loop Differential Real-Time Receiver
GPS	Global Positioning System
GPS/MET	GPS/Meteorology
GNSS-R	GNSS-Reflectometry
griPAU	GNSS Reflectometer Instrument for the Passive Advanced Unit
GRACE	Gravity Recovery and Climate Experiment
GTS	Global Telecommunication System
HFI	Hardy Function Interpolation
IAG	International Association of Geodesy
IEEC	Institute for Space Studies of Catalonia
IERS	International Earth Rotation Service
IEM	Integral Equation Method
IGS	International GNSS Service
IGOR	Integrated GPS and Occultation Receiver
IPT	Interference Pattern Technique
IPP	Ionosphere Pierce Point
IRNSS	India's Regional Navigation Satellite Systems
IRI	International Reference Ionospheric
ITRF	IERS Terrestrial Reference Frame
JPL	Jet Propulsion Laboratory
KA	Kirchho Approximations
KPO	KA in Physical Optics Approximation

KGO	Kirchhoff Geometrical Optics
LAAS	Local Area Augmentation System
LC	Linear Combination
LEO	Low Earth Orbit (satellite)
LHCP	Left-Hand Circular Polarization
LOS	Line-of-Sight
LS	Least Squares (adjustment)
MEO	Medium Earth Orbit
MIT	Massachusetts Institute of Technology
MSU	Microwave Sounder Unit
MSAS	Multifunction Satellite Augmentation System
MSS	Mean of the Square Slopes
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NMF	Niell Mapping Function
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
NOC	National Oceanography Centre
OCX	Operational Control System
PARIS	PAssive Reflectometry Interferometric System
PDF	Probability Density Function
PGGA	Permanent GPS Geodetic Array
PIT	PARIS Interferometric technique
PLL	Phase-Locked Loop
PNT	Positioning, Navigation and Timing
POD	Precise Orbit Determination
PPP	Precise Point Positioning
PWV	Precipitable Water Vapor
PRN	Pseudo-Random Noise
PVT	Position, Velocity and Time
RINEX	Receiver Independent Exchange
QZSS	Quasi-Zenith Satellite System
RFI	Radio Frequency Interference
RMS	Root Mean Square
RT	Radiative Transfer
RTK	Real-Time Kinematic
RO	Radio Occultation
RHCP	Right-Hand Circular Polarization
SA	Selective Availability
SAR	Synthetic Aperture Radar
SAC-C	Satellite de Aplicaciones Cientificas-C
SBAS	Ground- and Space-Based Augmentation Systems
SGR-ReSI	Space GPS Receiver-Remote Sensing Instrument
SHAO	Shanghai Astronomical Observatory

SLM	Single Layer Model
SMEX02	Soil Moisture Experiment 2002
SMIGOL	Soil Moisture Interference-pattern GNSS Observations at L-band
SMOS	Soil Moisture and Ocean Salinity
SMAP	Soil Moisture Active and Passive mission
SNR	Signal-to-Noise Ratio
SOL	Safety-of-Life
SSC	Surrey Space Centre
SSTL	Surrey Satellite Technology Limited
SD	Single Difference
SINEX	Software Independent Exchange (format)
SLM	Single Layer Model
SLR	Satellite Laser Ranging
SNR	Signal-to-Noise Ratio
SPM	Small Perturbation Method
SSA	Small Slope Approximation
SST	Satellite-Satellite Tracking
SSTL	Surrey Satellite Technology Limited
STD	Slant Tropospheric Delay
STEC	Slant Total Electron Content
SWH	Significant Wave Height
TEC	Total Electron Content
TriG	Tri-GNSS (GPS+Galileo+GLONASS)
TOPEX	Topography Experiment
TT&C	Tracking, Telemetry and Command
URSI	International Union of Radio Science
USAF	US Air Force
UT	Universal Time
VLBI	Very Long Baseline Interferometry
VMF	Vienna Mapping Functions
WAAF	Woodward Ambiguity Function
WGS	World Geodetic System
WVR	Water Vapor Radiometry
ZTD	Zenith Tropospheric Delay
ZHD	Zenith Hydrostatic Delay
ZWD	Zenith Wet Delay
Z-V	Zavorotny and Voronovich