Preliminary Investigation of GNSS-R Receiver Techniques

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Three types of GNSS receivers

- **Positioning**
  - Provision of accurate position, navigation and time information

- **Occultation**
  - Probing of atmospheric and ionospheric profiles

- **Reflectometry**
  - Remote sensing of the surface properties
Operating principle

- The reflection constitutes a signal propagation path of GNSS satellites.
- The delay of the GNSS reflected signal with respect to the direct line-of-sight signal, together with information on the receiver antenna position, the medium, and the GNSS satellite position, reveals the properties of the reflecting surface.
- For reflected signals from ocean surface, information such as ocean surface height, wind speed, wind direction, and sea ice condition can be retrieved.

GNSS-R remote sensing applications

- Atmosphere
  - Troposphere and ionosphere
- Ocean
  - Altimetry, wind speed and direction, salinity
  - Sea ice, pollution, Tsunami
- Land
  - Soil moisture, glacier, lake and wet
Past and Future GNSS-R Missions

- Ground based observations
- Airborne campaigns
- Space based observations
  - Space shuttle (SIR-C radar data)
  - UK-DMC (SSTL)
  - PARIS (ESA, passive reflectometry and interferometry system)
  - CYGNSS (NASA, cyclone GNSS)
GNSS-R Characteristics

- Based on a bistatic radar configuration
  - The transmitter and the receiver are not collocated.
  - Multistatic configuration: multiple transmitters (GNSS satellites) and receivers (LEO satellites)

- Ubiquitous GNSS signals
  - Stable and reliable
  - Global and fairly uniformly distributed

- Passive remote sensing

- Satisfactory temporal and spatial resolution

- Acceptable accuracy

- Weak signals
The interaction between the atmosphere and ocean, i.e., the boundary layer, is important in governing the weather.

GNSS-R is a viable technique that can facilitate the observation in an acceptable spatial and temporal scale.

Motivation: Studies of the eddies are essential to the understanding of the dynamics of ocean circulation

- Large-scale meridional transport of heat by eddies
- Mass transport by large-scale currents through eddy-mean flow interaction
- Dominant source of sea surface height variability

Global measurements of meso-scale eddies

- Height: 5 cm to 20 cm
- Spatial scale: 10 km to 100 km
- Temporal evolution: 1 week to 1 month

Adapted from JPL
Significances of GNSS-R

- The GNSS-R data can augment the GNSS-RO data in the inversion process.
  - Atmosphere and ionosphere observations
  - Boundary condition
- Some processing techniques of GNSS-R and GNSS-RO are similar.
Objectives

- Develop GNSS-R signal reception and processing techniques

Tasks

- Link budget analysis of GNSS reflected signals
- Antenna array techniques for GNSS-R signal processing
- GNSS-R signal analysis techniques (delay-Doppler map, …)
The reflected signals are much weaker than the direct line-of-sight signals.

The reflected signal power further depends on:
- Scattering cross-section coefficient
- Fresnel zone area
Scattering Cross-Section Coefficient

- Characterizes the signal reflection and scattering property.
- Let the scattering vector be

\[ q = \frac{2\pi}{\lambda} \left( \frac{p - p_t}{\|p - p_t\|} + \frac{p - p_r}{\|p - p_r\|} \right) \]

- The normalized bistatic cross section can be computed as

\[ \sigma_0 = \pi |\mathcal{R}|^2 \frac{|q|^4}{q_z^3} f\left(\frac{q_z}{q_z}\right) \]

- The Fresnel coefficient is

\[ \mathcal{R} = \frac{1}{2} \left( \frac{\varepsilon \cos \eta - \sqrt{\varepsilon - \sin^2 \eta}}{\varepsilon \cos \eta + \sqrt{\varepsilon - \sin^2 \eta}} - \frac{\cos \eta - \sqrt{\varepsilon - \sin^2 \eta}}{\cos \eta + \sqrt{\varepsilon - \sin^2 \eta}} \right) \]
## GPS L1 Reflection Signal

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver altitude (km)</td>
<td>720</td>
</tr>
<tr>
<td>Incidence angle (deg)</td>
<td>10</td>
</tr>
<tr>
<td>EIRP (dBW)</td>
<td>27.43</td>
</tr>
<tr>
<td>Spreading loss to the specular point (dB)</td>
<td>182.53</td>
</tr>
<tr>
<td>Reflection zone (km²)</td>
<td>659.95</td>
</tr>
<tr>
<td>Wind speed (m/s)</td>
<td>12</td>
</tr>
<tr>
<td>Scattering cross-section coefficient</td>
<td>11.07</td>
</tr>
<tr>
<td>Reflected power at the Fresnel zone (dBW)</td>
<td>-31.56</td>
</tr>
<tr>
<td>Receiver antenna gain (dBi)</td>
<td>10</td>
</tr>
<tr>
<td>Received power (dBW)</td>
<td>-175.23</td>
</tr>
<tr>
<td>Pre-correlation C/N (dB)</td>
<td>-37.15</td>
</tr>
<tr>
<td>Coherent integration gain (dB)</td>
<td>33.11</td>
</tr>
<tr>
<td>Noncoherent integration gain (dB)</td>
<td>10</td>
</tr>
<tr>
<td>Squaring loss (dB)</td>
<td>6.69</td>
</tr>
<tr>
<td>Post-correlation C/N (dB)</td>
<td>-2.74</td>
</tr>
</tbody>
</table>
In comparison with the direct line-of-sight signals, the reflected/scattered signals are subject to additional code phase delays and Doppler shifts.

Correlation operations are performed in the reception and de-spreading of the incoming signals:
- Local carrier and code replica
- Power at different code phase delays and Doppler frequencies

Delay Doppler map reveals the power distribution of the reflected signal for different delays and Doppler frequencies with respect to the specular point.
- Peak power point → Height
- Power → reflectivity, wind speed
- Variation of the power → Roughness
The reflected power is

\[ |Y(\tau, f_D)|^2 = \iint \left( \frac{P_t G_t}{4\pi \| p - p_t \|^2} \right) \left( \frac{\sigma_0}{4\pi \| p - p_r \|^2} \right) \left( \frac{G_r \lambda^2}{4\pi} \right) \chi^2(\tau, f_D, p) dp \]

The Woodward ambiguity function represents the time response of a filter matched to a finite energy signal.

The support in the integrand is the intersection of four spatial zones

- The receiver antenna footprint
- The annulus zone defined by the autocorrelation function
- The Doppler zone defined by the sinc function
- The scattering cross section coefficient
Depending on the sea state, the delay Doppler map may vary.
As the reflected signals are relatively weak, it is desired to enhance the signal strength by employing antenna array techniques. Beam forming algorithms are developed and applied to receive GNSS signals.
**Navigation Satellites**

- **GNSS (Global Navigation Satellite System)**
  - GPS (USA)
  - GLONASS (Russia)
  - Galileo (European Union)
  - BDS (China)

- **RNSS (Regional Navigation Satellite System)**
  - QZSS (Japan)
  - IRNSS (India)
  - BDS today (China)

- **SBAS (Space-Based Augmentation System)**
  - WAAS (USA)
  - EGNOS (European Union)
  - MSAS (Japan)
  - GAGAN (India)
  - SDCM (Russia)
Consider the case of an LEO at 720 km, 72-deg inclination

GPS-R
The mean observation period of the segments is about 45.60 minute and the standard deviation of the observation segments is 15.93 minute.

SBAS-R
The observation period of the SBAS satellite is relatively long and consistent with a mean value of 50.92 minute and standard deviation of 6.41 minute.

RNSS-R (QZSS)
The mean observation period is 51.38 minute and the standard deviation is 4.49 minute.
Conclusions

- GNSS-R is an important technique
  - Complementing and augmenting GNSS-RO techniques
  - Boundary layer
  - Coupling effects
  - Potential disaster mitigation applications (Tsunami monitoring, Typhoon detection)
  - Viable to FORMOSAT-7 program

A preliminary study on GNSS-R signal reception and processing is performed.

Exploring signals of opportunity from SBASs and RNSSs may augment the GNSS reflectometry mission.
Thank you