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A real-time GNSS-R system based on software-defined radio and graphics processing units

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Abstract

Reflected signals of the Global Navigation Satellite System (GNSS) from the sea or land surface can be utilized to deduce and monitor physical and geophysical parameters of the reflecting area. Unlike most other remote sensing techniques, GNSS-Reflectometry (GNSS-R) operates as a passive radar that takes advantage from the increasing number of navigation satellites that broadcast their L-band signals. Thereby, most of the GNSS-R receiver architectures are based on dedicated hardware solutions. Software-defined radio (SDR) technology has advanced in the recent years and enabled signal processing in real-time, which makes it an ideal candidate for the realization of a flexible GNSS-R system. Additionally, modern commodity graphic cards, which offer massive parallel computing performances, allow to handle the whole signal processing chain without interfering with the PC's CPU. Thus, this paper describes a GNSS-R system which has been developed on the principles of software-defined radio supported by General Purpose Graphics Processing Units (GPGPUs), and presents results from initial field tests which confirm the anticipated capability of the system.
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Keywords: GNSS-Reflectometry; Software-defined radio; Graphics processing units

1. Introduction

Global Navigation Satellite System (GNSS) applications usually process the received signals to determine position, velocity or time of the receiver, or derive information about the atmosphere or ionosphere (see Hofmann-Wellenhof et al., 2001). In general, GNSS signals are transmitted from satellites and are expected to be received by a ground based antenna, avoiding multi-path or reflections in order to achieve utmost high precision positioning results. Nevertheless, for a variety of applications (e.g. Egido et al., 2009) the information from reflected signals can become a valuable data source, from which one can deduce (geo-) physical properties. Since most GNSS antennas are designed to receive only the direct right-hand circular polarized (RHCP) signals, it is necessary to deploy a dedicated antenna which is capable to detect the reflected signals which have changed to left-hand circular polarization (LHCP) after being reflected (see Fig. 1). Moreover, in most of the cases GNSS-Reflectometry (GNSS-R) antennas are not pointed towards the sky, but either looking downwards or at least being tilted towards the horizon in order to receive the reflected signals within the main lobe of the antenna beam pattern. Depending on the application and the area of interest, GNSS-R systems can be mounted close to the ground (e.g. Zhang et al., 2007), flown on an airplane (e.g. Ruffini et al., 2004) or even installed on board of a satellite (e.g. Clarizia et al., 2008). In order to measure instrumental delay changes due to platform movement or instrumental characteristics it is common to utilize two GNSS antennas, whereas one is dedicated to track direct RHCP GNSS signals and the other one is assigned to

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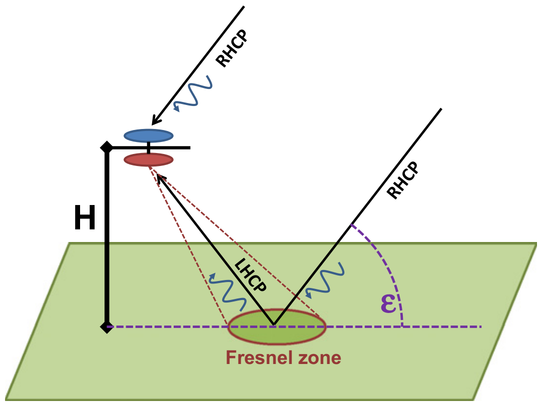

Fig. 1. Basic principle of GNSS-R. RHCP signals transmitted from a GNSS satellite are reflected on the Earth's surface and change polarization (to LHCP). These signals can be received, analyzed and used to deduce geophysical parameters of the reflecting surface.

receive the reflected LHCP signals. Thereby the diameter of the nth Fresnel zone assigned to the reflecting area can be determined by

$$D_F = \sqrt{\left(\frac{n\lambda d_1 d_2}{d_1 + d_2}\right)} \tag{1}$$

where d_1 and d_2 represent the distance of the transmitter and receiver from the reflecting surface and λ represents the corresponding wavelength of the observed signal. For ground based GNSS-R systems operating on the GPS L1 frequency ($\lambda = 0.19$ m) and which are only a few 10's of meters above the reflecting surface one can set $\frac{d_1}{d1+d_2} \approx 1$ which simplifies Eq. (1) to

$$D_F = 0.436\sqrt{nd_2}. \tag{2}$$

Fig. 1 depicts the basic modes of operation of a GNSS-R system. Such a system can be used to measure the reflection characteristics by comparing the LHCP signals with the replica version of the GNSS code, yielding delay or delay-doppler information which can be assigned to the underlying geophysical signal. If the information from the RHCP antenna is considered as well, the instrument turns into an altimeter when arrival times of direct and reflected signals are being compared. As shown in Fig. 1 the LHCP signal travels over a longer path than the direct RHCP signal. Assuming that both antennas are located at the same location or that the distance between them is well known one can express this excess delay as

$$\Delta\tau = \frac{2H}{c}\sin\varepsilon \tag{3}$$

where ε is the elevation angle toward the satellite as seen from the ground point, H is the height of the receiver above the plane surface and c represents the speed of light. Thus, measuring the delay of the LHCP signal w.r.t. the RHCP signal allows to derive the height of the receiver above the reflecting surface. Additionally, a comparison of RHCP and LHCP signal strength allows to derive the attenuation caused by the reflection and thus provides radiometric information about the ground surface as well. Other studies based on single GNSS antenna systems (e.g. Larson et al., 2008) reveal that this information can be used to derive geophysical parameters like e.g. soil moisture.

2. GNSS-R by means of software-defined radio

For the development of a GNSS-R software receiver one still relies on hardware parts which receive the analog signals and turn them into a digital data-stream that can be processed by an off-the-shelf PC. In order to keep the overall cost of the system low, it is necessary to rely on commercial products as much as possible and only develop hardware components when no other existing solution can be found. This concept has been applied to all components throughout the development and operational phase of the GNSS-R system and is described in the following sections as well.

2.1. GNSS antennas

A few GNSS antenna manufacturers (e.g. Antcom) are offering LHCP patch antennas with the same configuration as the RHCP types are sold. Thus, one can purchase RHCP and LHCP antennas which have the same beam pattern and low noise amplifiers (LNAs) but are only differing in their polarization sensitivity.

Starting with such two antennas, a two meter long pole was designed to mount the antennas on one end. In order to avoid that a signal can enter both antennas, two disk shaped aluminum plates are placed below each antenna. Fig. 2 depicts the pole with the two GNSS antennas mounted on the head, whereas the RHCP type is intended to be oriented toward zenith in order to receive the direct signals. The LHCP antenna on the opposite site is sensitive to reflected waves from the ground or objects below. Antenna cables with identical electrical length are guided inside the pole. This pole can be mounted easily on buildings or other infrastructure which allows to receive reflected signals from a wide area below the antenna site.

2.2. Hardware front–end and A/D converter

All modern GNSS are transmitting their civil and/or military signals in L-band whereas most of the systems facilitate at least two different frequencies in order to remove dispersive delay effects caused by trans-ionospheric propagation. Therefore a receiver front–end must be flexible enough to cover a variety of L-band frequencies as well as support a sufficiently wide bandwidth to capture the spread-spectrum signals. Although for the initial tests only L1 signals have been utilized it is preferable to have a hardware front–end that allows to receive other GNSS signals with the same hardware by controlling the RF center frequency from the software receiver. The community around the software-defined radio (SDR) has been dealing with

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