THE LIGHT AIRBORNE REFLECTOMETER FOR GNSS-R OBSERVATIONS (LARGO) INSTRUMENT: INITIAL RESULTS FROM AIRBORNE AND ROVER FIELD CAMPAIGNS

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ABSTRACT

Global Navigation Satellite Systems (GNSS)-Reflectometry (GNSS-R) has proved to be a useful technique for the estimation of Soil Moisture (SM). In the past 10 years, different techniques such as the Interference Pattern Technique (IPT), the Interferometric Complex Field (ICF) or power measurements of direct and reflected GNSS signals have been used. This work presents a reflectometer concept that can be used for air-borne, Unmanned Aerial Vehicle (UAV), car-borne, and ground-based measurements. It also presents the hardware implementation and the data acquisition scheme. An algorithm for the estimation of the reflectivity of the surface under observation has been developed and compared to concurrent radiometric measurements. Initial results from an airborne field experiment have shown a good correlation between both data sets.

***Index Terms*—** GNSS-R, Soil Moisture, Reflectometry, Radiometry, L-Band.

1. INTRODUCTION

In the last 15 years, several GNSS-R techniques have been used for the retrieval of SM. In 1998, it was demonstrated that the Brewster angle position could be determined with GNSS-R observations using a vertically polarized antenna pointing to the horizon [1]. Later, this approach was followed to retrieve SM maps using the SMIGOL instrument [2, 3]. A similar approach, with geodetic Right Hand Circular Polarization (RHCP) antennas looking at the zenith was used to infer the relative water content using low grazing angles observations [4, 5]. In this approach, which is also known as the Signal to Noise Ratio (SNR)-analysis, the reflected signal comes from the sidelobes of the antenna pattern. In 2004, airborne field campaigns related to the SMEX02 experiment demonstrated that the Left Hand Circular Polarization (LHCP) Global Positioning System (GPS) reflected power was sensitive to the SM content [6, 7]. One step forward to this approach was the use of the ICF in order to estimate the SM content [8, 9].

This work presents in Section 2 a reflectometer concept and its hardware implementation intended for air-borne, UAV, car-borne and ground-based platforms. In Section 3 the retrieval algorithm for the reflectivity parameter is described. In Section 4 the initial results from an airborne field campaign and its comparison with radiometric data are shown. Finally, Section 5 presents the conclusions and future work.

2. LARGO REFLECTOMETER

The LARGO reflectometer was first presented in [10]. It is a dual-channel instrument, see Fig. 1; one channel acquires the direct GNSS signals with a RHCP active antenna; the other channel acquires the reflected GNSS signals with a LHCP active antenna, since GNSS signals for elevation angles higher than 30° become LHCP after reflection. The antennas are fed using a T-bias for each channel. After that, a variable attenuator is used to avoid saturating the back-end receivers. To avoid undesired effects of out-of-band radio frequency interference there is a SAW filter after the variable attenuator in each channel. After the SAW filter the corresponding back-

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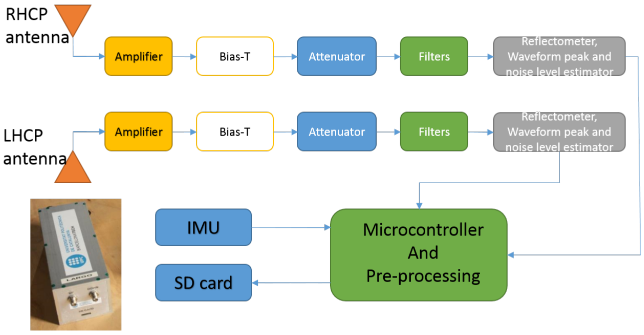

Fig. 1: LARGO Block diagram.

end receiver samples the received signal, correlates it with a clean replica of the satellite code, stores the peak correlation value referenced to the noise level, which is the SNR, and estimates the noise level. From that signal also the GPS navigation solution is estimated. Finally, in the case of airborne or UAV platforms, the information of an Inertial Measurement Unit (IMU) is added in order to infer the platform dynamics and obtain the antenna gain for each of the satellites in view. A picture of the LARGO instrument is shown in Fig. 1 (bottom left). Its size is 25x10x8 cm and it weights 2.5 kg.

3. REFLECTIVITY ESTIMATION ALGORITHM

Considering the radar equation, and the fact that the coherent component dominates against the incoherent component for bare soil scenarios in airborne and ground-based conditions [2, 6, 9], the reflectivity from RHCP transmission and LHCP reception can be estimated as follows:

$$\widehat{\Gamma_{RL}} = \beta \cdot \frac{G_{R_D}(\theta,\phi)\cdot\rho_D(\theta,\phi)\cdot SNR_R}{G_{R_R}(\theta,\phi)\cdot\rho_R(\theta,\phi)\cdot SNR_D}, \qquad (1)$$

$$\beta = \frac{T_{A_R} + T_{R_R}}{T_{A_D} + T_{R_D}}, \qquad (2)$$

where β is a correction factor due to different antenna and receiver's noise temperature, $G_{R_D}(\theta,\phi)$ and $G_{R_R}(\theta,\phi)$ are the antenna gain for the direct and reflected signal channel respectively, θ and ϕ are the antenna coordinates which indicate from where the input signal is coming from, $\rho_D(\theta,\phi)$ and $\rho_R(\theta,\phi)$ are the polarization mismatch factor between the incoming signal and the antenna polarization coefficient for the direct and reflected channels respectively, SNR_D and SNR_R are the signal to noise ratio computed at the reflectometer back-end receivers for the direct and reflected channels, T_{A_R} and T_{A_D} are the antenna noise temperature for the reflected and direct channels, and finally, T_{R_R} and T_{R_D} are the receiver's equivalent noise temperature for the reflected and direct channels respectively. Note that, $\beta > 1$ if both channels gain are balanced, since the antenna noise temperature for the reflected channel should be theoretically higher than for the direct channel. In case they are not balanced, this factor must be estimated and corrected. The antenna pattern from the antennas in LARGO was measured in an anechoic chamber, which means that the antenna gain and the polarization mismatch factor are characterized. Consequently the reflectivity can be estimated. Then, reflectivity can be then related to the terrain dielectric constant and to the soil moisture content using theoretical models. The surface roughness parameter must be taken into account in this inversion process.

4. INITIAL AIRBORNE FIELD CAMPAIGN RESULTS

4.1. Field Campaign description

In order to test the performance of the LARGO reflectometer, three air-borne and car-borne field campaigns have been performed in the states of Victoria and New South Wales, Australia, in collaboration with Monash University during September-November 2013.

In the airborne field campaigns the Polarimetric L-Band Microwave Radiometer (PLMR) was flown with the LARGO reflectometer. The PLMR is a polarimetric radiometer (horizontal and vertical polarization) with 6 antenna beams that measures brightness temperature with an accuracy of 0.7K in the range of 0-350K [11] in each channel. Figure 2 shows the aircraft set-up.

In the car-borne field campaign a buggy was used for the reflectometer installation. Figure 3 shows the instrument installation with the up-looking and down-looking antennas at the edge of the metallic item bar. In selected areas of the Yanco region, intensive soil moisture sampling was performed concurrently to the flights using HydraProbes.

4.2. Initial results and discussion

The first airborne field campaign, followed the route shown in Fig. 4. The followed route started at Melbourne, it went to French island to get measurements over the sea surface, and finally it ended on the Yanco region, where several consecutive flight tracks through a determined area, where ground-truth information is available, were done.

Figure 5 shows two reflectivity images retrieved from the field campaign: zone 1, (Fig. 5a), where there is a lake and the difference in reflectivity between land and sea is observed; and zone 2, (Fig. 5b) where there are three lakes, and also the changes in the reflectivity values are clearly observed between the lakes and land. The brightness temperatures retrieved at vertical and horizontal polarization with the PLMR radiometer (big squares) are shown at the background of the reflectivity retrievals (round circles). In the brightness temperature results, blue values indicate low brightness temperature ($\sim$ 100K, associated to water), whereas red indicate high brightness temperature ($\sim$ 270K, associated to dry land). In reflectivity, blue means high reflectivity (normally associated

Fig. 2: Air-borne field experiment set-up. Top figure shows the plane and the PLMR radiometer position. Bottom left figure shows the down-looking antenna. Bottom right figure shows the up-looking antenna installed on the plane.

to high water contents), whereas red means low reflectivity. These indicates, as expected, that the brightness temperatures and the reflectivity parameter are highly correlated. Notice that there is more than one track followed in the reflectivity image: two satellites for Fig. 5a and three satellites for Fig. 5b. This occurs because more than one satellite is being monitored real-time at each sampling time, which allows to obtain higher spatial coverage.

5. CONCLUSIONS AND FUTURE WORK

In this work the LARGO reflectometer concept and hardware implementation are described. LARGO is a reflectometer intended for air-borne, UAV, car-borne and ground-based experiments. Then, the reflectivity retrieval algorithm is introduced with all the parameters that must be taken into account in order to obtain valid reflectivity retrievals. Finally, a field campaign conducted in the states of the Victoria and New South Wales, Australia. As expected, preliminary data shows correlation between reflectivity obtained from LARGO and brightness temperature at vertical polarization obtained from PLMR.

At present LARGO weights 2.5 kg. A low-weight LARGO version (< 1 kg) suitable for UAV platforms is under development, as well as an algorithm to derive SM maps from the reflectivity values measured by LARGO. Preliminary SM maps will be shown at the conference.

Fig. 3: Car-borne field experiment set-up.

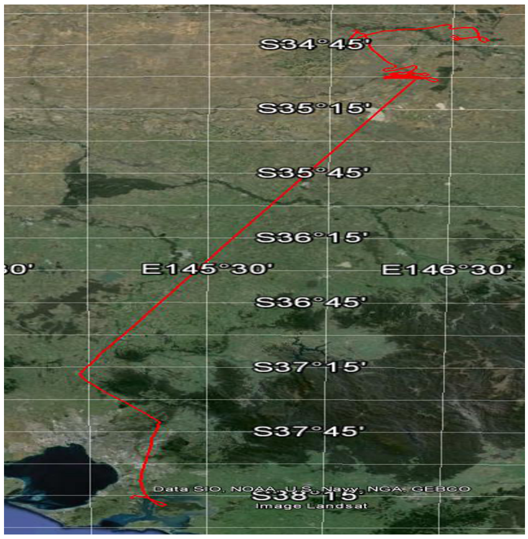

Fig. 4: Ground-track of the field experiment.

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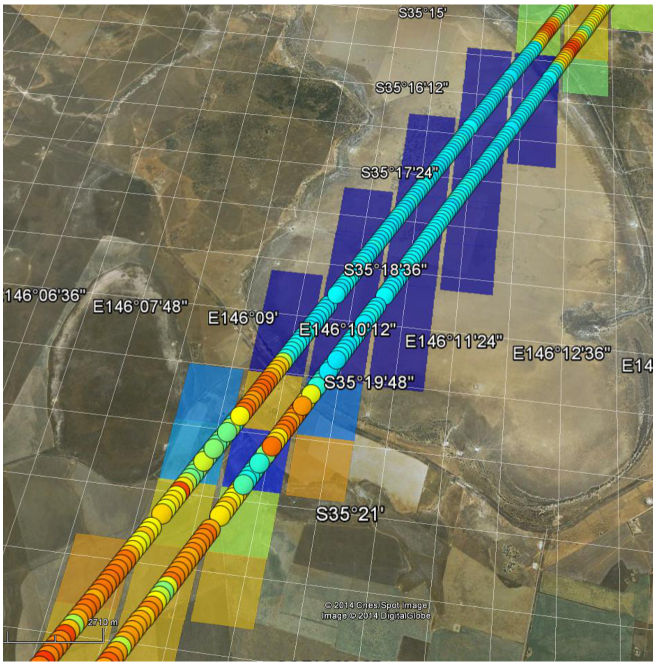
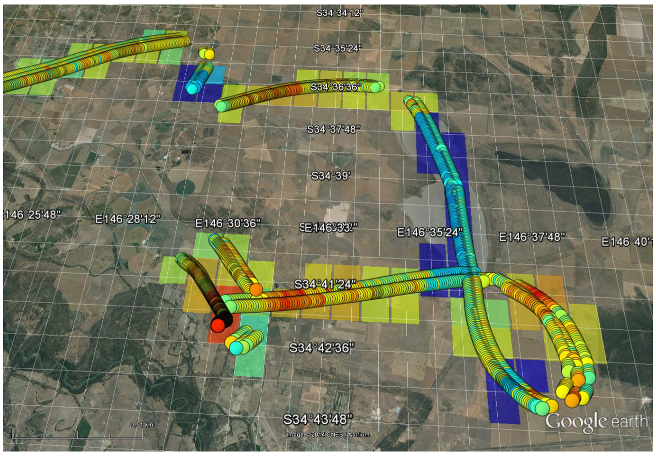


(a) Zone 1.



(b) Zone 2.

Fig. 5: Two different results of the LARGO scatterometer. PLMR data is represented with big squares. Low brightness temperature (associated to water) is represented in blue. High brightness temperature (associated to dry land) is represented in red. LARGO data is represented with round circles. Blue in reflectivity indicates high reflectivity (associated to water) whereas red in reflectivity means low reflectivity.