THE NEW ALGORITHM FOR RETRIEVAL OF SOIL MOISTURE AND SURFACE ROUGHNESS FROM GNSS REFLECTOMETRY

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ABSTRACT

In this paper we propose a new simple algorithm for data processing of GNSS reflectometry. At first step of data processing of interference patterns the algorithm allows to retrieve the modulus of the reflection coefficient and then retrieve soil moisture and surface roughness of the soil. This method allows to not take into account information about the antenna pattern and height of GNSS antenna, and also excludes the impact of geodesic relief roughness. The proposed methodology was used for the retrieval moisture and surface roughness of soil using data recorded GPS receiver on a vertical polarization.

Index Terms— Global Navigation Satellite System Reflectometry (GNSS-R), soil moisture, reflection coefficient, interference patterns

1. INTRODUCTION

Global Navigation Satellite System (GNSS) reflectometry techniques have been widely used for soil moisture and surface roughness retrieval in L-band [1]-[3]. Basically, moisture and surface roughness of the soil are retrieved by fitting a theoretically calculated interference pattern to the experimentally measured one. In the earlier methodologies, such parameters as antenna pattern, antenna height above the surface of the soil were to be retrieved in addition to soil moisture and surface roughness. At that, the geodesic irregularities of the lay of land were also to be taken into account when calculating the theoretical curve of the interference pattern. These factors make the problem of retrieving the moisture and surface roughness of soil multivariate and substantially increases the error of retrieved parameters. Moreover, there is currently no algorithm of data processing of interference patterns that would allow to retrieve the reflection coefficient using GNSS reflectometry techniques. In the next section describes a method to measure the module of the reflection coefficient of electromagnetic waves from the soil surface with using a GPS receiver. The method is applied to measure the modulus of the reflection coefficient out of recorded interference patterns by GPS receiver, on vertical polarization. Finally, a moisture and surface roughness of the soil is retrieved out of obtained module of reflection coefficient.

2. METHODOLOGY OF MEASURING MODULE OF REFLECTION COEFFICIENT FROM GNSS REFLECTOMETRY

The total power recoded by GPS receiver placed above the rough surface of bare soil, can be calculated using the formula [3]:

$$P(\theta) = F(\theta) \cdot \left|1 + \left|\Gamma(\theta)\right| e^{i\Delta\Phi(\theta)}\right|^2, \quad (1)$$

where $F(\theta)$ – antenna pattern, $|\Gamma(\theta)|$ – module of complex reflection coefficient, $\Gamma(\theta)$, of a plane electromagnetic wave (polarized vertically or horizontally) from a rough surface, $\Delta\Phi(\theta)=\gamma(\theta)+\varphi(\theta)$, $\gamma(\theta)$ – phase of complex reflection coefficient, $\varphi(\theta)=2k_0 h\cdot\cos(\theta)$ – the phase difference between the direct wave (propagating in a straight line from the satellite to the receiver) and the reflected wave from the soil surface, $k_0=2\pi f/c$ – wave number of vacuum, f=1575.42 MHz – the GPS working frequency, h – height of antenna of GPS receiver, θ – angle of incidence of electromagnetic waves on the surface of the soil, c – velocity of light in vacuum.

A simple model (1) allows to derive an analytic expression for calculating the module of reflection coefficient from the interference pattern recorded by GPS receiver. Discrete points of the maximum $P_{up}(\theta_{up,\,n})$ and minimum $P_{low}(\theta_{low,\,n})$ power of interference pattern corresponds to the angles, which are found from the equations $\Delta\Phi_{up}(\theta_{up,n})=2\pi n$ and $\Delta\Phi_{low}(\theta_{low,n})=\pi(2n+1)$, где n=0, 1, 2, …. At discrete points of maximum and minimum can be made upper $P_{up}(\theta)$ and lower $P_{low}(\theta)$ envelopes of the interference pattern:

$$P_{up}(\theta)=F(\theta)\cdot(1+|\Gamma(\theta)|)^2, \quad (2)$$

$$P_{low}(\theta)=F(\theta)\cdot(1-|\Gamma(\theta)|)^2, \quad (3)$$

using interpolation algorithm and nodal points ($\theta_{up,n}$, $P_{up}(\theta_{up,\ n})$) и ($\theta_{low,n}$, $P_{low}(\theta_{low,n})$). From (2) and (3) is now easy to obtain an expression for the module of the reflection coefficient based on measured envelopes of interference pattern:

$$|\Gamma(\theta)| = \frac{\sqrt{P_{up}(\theta)} - \sqrt{P_{low}(\theta)}}{\sqrt{P_{up}(\theta)} + \sqrt{P_{low}(\theta)}}. \quad (4)$$

Note, this formula is valid as a vertical well as a horizontal and circular polarization, if the receiver is recorded corresponding polarization. In this paper to describe the module of the reflection coefficient from a rough surface is used the formula [4]:

$$|\Gamma(\theta)| = |R(\theta, \varepsilon(f, m_c, W_W)|e^{-2(k_0\sigma_r)^2 \cos^2\theta}, \quad (5)$$

where $R(\theta,\ \varepsilon(f,\ m_c,\ W_W))$ – Fresnel's reflection coefficient, $\varepsilon(f,\ m_c,\ W_W)$ – relative complex permittivity of soil, m_c and W_W – relative gravimetric clay and volumetric water content in soil, respectively, σ_r – root mean square height of surface roughness.

The relative complex permittivity, $\varepsilon(f,\ m_c,\ W_W)$, of moist soil was calculated using the experimentally-based model permittivity of soil [5]. This model takes into account the type of soil, its mineral composition, moisture content, the frequency of the electromagnetic field, as well as phase transitions between different types of water in the soil.

3. RETRIEVAL SOIL MOISTURE AND SURFACE ROUGHNESS BASED ON NEW ALGORITHM

Testing of proposed algorithm was carried out based on the field measurement of interference pattern recorded by the GPS receiver at vertical polarization [3] for the bare soil. Experimental interference patterns from [3] are shown on Fig. 1. Using formula (4), upper, $P_{up}(\theta)$, and lower, $P_{low}(\theta)$, envelopes which have been determined from the interference pattern see Fig. 1, there was calculated the module of reflection coefficient see Fig. 2. The module of reflection coefficient has a typical minimum at Brewster angle (19.6°) see Fig. 2, which corresponds to the notch at the interference pattern see Fig. 1.

On the basis of expression (5) and using the model of the relative complex permittivity of moist soil [5] for a given value of the clay content in the soil m_c=0.02 g/g were retrieved volumetric water content, W_w, and the surface roughness σ_r of soil. The retrieved value of the volumetric water content of soil (0.205 cm^3/cm^3) close to values given in [3]. Retrieved value of surface roughness were less than the value (~2 cm) measured in [3]. This can be explained by that the soil surface may be considered as smooth in the whole range angles of incident electromagnetic field, based on the Rayleigh's criterion for a smooth surface ($\sigma_r \cdot \cos\theta < \lambda/4\pi$).

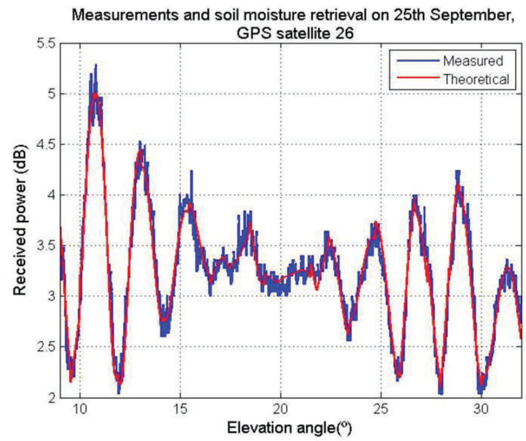

Fig. 1. Measured by GPS receiver interference power pattern borrowed from [3]. Volumetric soil moisture at the depth of 5 cm and 20 cm were equal to 0.21 and 0.23 (cm^3/cm^3), respectively [3].

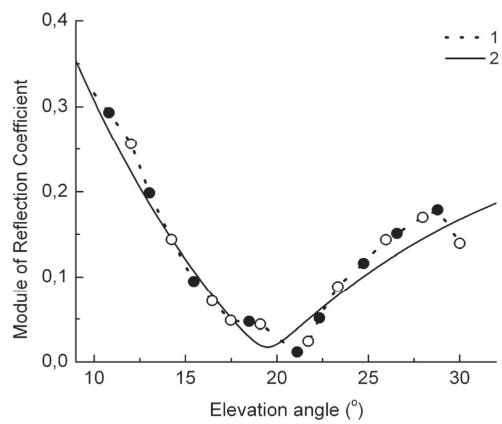

Fig. 2. Module of reflection coefficient. 1 - determined by (4), 2 - calculated by (5) with the values of fitted soil moisture (W_W=0.205 cm^3/cm^3) and surface roughness σ_r=0.0 cm. Open circle and full circles correspond to the reflection coefficients at the minimums and maximums of the interference pattern see Fig.1, respectively.

4. CONCLUSION

In this paper, we were proposed a new algorithm for retrieving the moisture and surface roughness of the soil with using of GNSS reflectometry techniques. This method allows to not take into account information about the antenna pattern and height of GPS antenna, and also excludes the impact of geodesic relief roughness near GPS receiver. Also, suggested algorithm allows to measure the module of reflection coefficient of waves coming upon the surface of the soil from the GPS satellite as a function of incidence angle. The retrieved moisture and surface roughness of soil are in a good agreement with the values measured independently. The proposed new methodology greatly simplifies the processing of GNSS reflectometry data aimed at sensing soil moisture.

5. REFERENCES

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