A UBIQUITOUS GNSS-R APPROACH USING SPINNING SMARTPHONE ONBOARD A SMALL UAS

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ABSTRACT

This paper presents a practical technique to estimate surface reflectivity using two sets of Global navigation satellite system (GNSS) measurements. A down-facing smartphone (attached to a ground plate) on a Unmanned Aircraft Systems (UAS) collects reflected signals while another identical phone is located on the ground that provides reference data in an open area. Both drone and ground units are rotated with a constant speed to mitigate radiation pattern irregularities of smartphone's in-built GNSS antenna. Reflectivity at various elevation angles and locations are obtained by taking the logarithmic difference between measurements (GNSS carrier-to-noise density ratio C/N_0) on the UAS and in the open area. The estimated reflectivity can be utilized for quantification of surface soil moisture and vegetation water content that is needed for various precision agriculture and spaceborne product validation efforts.

***Index Terms*—** Smartphone, Android, GNSS, vegetation, UAS, reflectivity.

1. INTRODUCTION

Global Navigation Satellite System (GNSS) Reflectometry (GNSS-R) is the most studied signals of opportunity approach that harnesses reflected GNSS signals (multipath) for remote sensing at L-band [1, 2]. Traditionally, almost all GNSS-R approaches have been investigated through custom-built, expensive systems or networks of geodetic receivers. For broader adaptation of the GNSS-R techniques, we recently conjectured that a down-facing smartphone integrated into a multi-copter UAS platform can operate as a ubiquitous GNSS-R system where reflected GNSS signals are collected via built-in GNSS chip of the smartphone [3]. The preliminary results of the study indicated that reflected signals are highly correlated with surface features, including high reflectivity over ponds, sensitivity to land crop types, and moisture in the soil, consistent with the previous GNSS-R experiments with custom-built equipment. However, the poor quality of in-built GNSS antenna was found to be the main pitfall in the use of GNSSR techniques from smartphones. The received signal strength was shown to be significantly modified by the orientation of smartphone due to irregular radiation patterns of its GNSS antenna. In principle, this issue can be compensated by characterizing the antenna as a look-up table ahead of time and taking advantage of its embedded sensors for predicting the true orientation since the pattern is time-invariant.

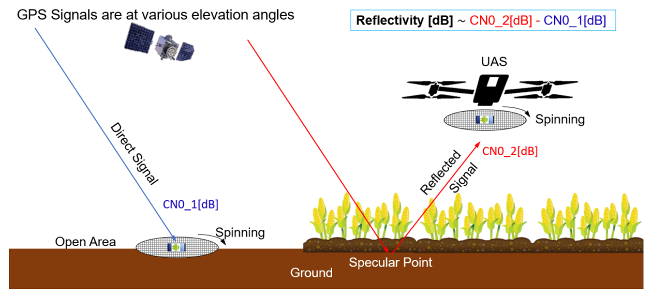

Fig. 1. Measurement configuration.

In this paper, we propose a novel approach to lessen the impact of the antenna on the received signal by spinning the smartphone on a rotating ground plate, which requires no explicit knowledge of antenna pattern characteristics. The idea of mechanically rotating antennas has been previously used for side lobe suppression of array antennas [4]. As illustrated in Figure 1, our proposed experiment setup involves a UAS equipped with a smartphone (or a custom GNSS receiver antenna) on the bottom of the UAS frame, and a separate phone (or a custom receiver antenna) facing upward on the ground that provides reference data in an open area. Both phones (or custom receiver antennas) are spun with a constant rotation speed to sample the antenna uniformly. Both phones (or antennas) are also placed on a circular mesh ground plate to isolate direct and reflected signals.

Our working hypothesis is that spinning the smartphone over a full rotation averages the antenna pattern and makes the acquired signal immune to the antenna pattern variations (dips/nulls) within typical orientation changes that a UAS experiences. To test this idea, we recently conducted several experiments that include various configurations on the ground and in flights. We first investigate the impact of the rotation speed on the received signal strength for roughly a 4-hour time period. Second, we compare the results from measurements with the phone on a small UAS and the ground. The preliminary results indicate that spinning the phones with at

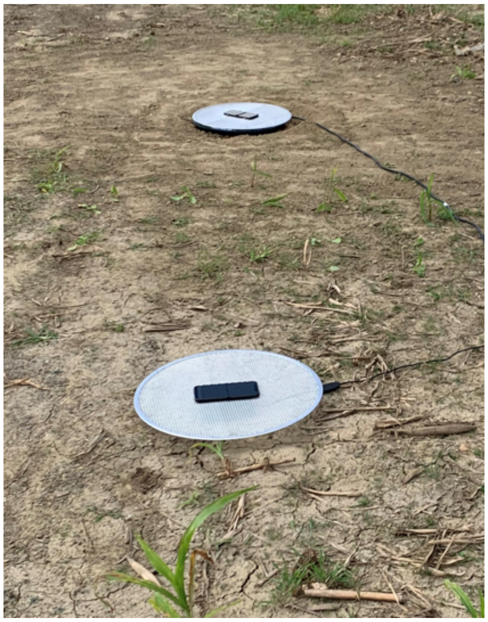

Fig. 2. Experiment with rotating and stationary phones, placed on the ground. The phone in the back rotates with a constant speed while the one in the front stays stationary towards a certain direction

Fig. 3. Experiment with rotating phones, placed on the ground and under a quad copter. Both phones with ground plate spin at the same speed. A picture of the drone step up is shown.

least one full rotation every second (60 revolutions per minute (RPM)) makes the received signal quite uniform compared to the stationary phone that typically has dip/nulls. The data collected by the phone on the UAS is mostly lower than the direct signal acquired with the unit on the ground as expected, but there are offsets in the difference data, where the sources of biases might be due to variable angular differences between two units as the drone moves.

2. DATA AND METHODOLOGY

The possibility for remote sensing of the environment (e.g., soil moisture, vegetation water content) using mass-market platforms (smartphones and drones) has significant implications for the agriculture economy, ushering in a host of precision agriculture applications [5]. However, the poor quality of built-in GNSS antennas make GNNS-R approach very challenging. In other words, the radiation pattern of built-in antennas are highly irregular and include nulls, depending on the orientation of the phone with respect to GNSS transmitters. As a result, the received signal is blended with antenna properties, and it is hard to disentangle the antenna effects from the signal that interacts with the environment. While it is possible to fully characterize the antenna pattern carefully and remove it from the measured signal, creating phone-dependent antenna pattern characterizations can be an undesirable workload for in-field experiments. Instead, our proposed approach spins the phone one full rotation within the integration time which can be set to one second. Spinning the phone allows to sample the received signal in different azimuth directions. This averages the pattern and makes it much more uniform.

To demonstrate the impact of spinning on the received signal, we conducted time-series experiments on four different days (October 24, 26, 27 and November 1, 2021). For each day, we used two phones attached to a ground plate and placed on the surface as shown in Fig. 2. While one phone rotates with a constant speed (e.g., 30, 60, 90, or 120 RPM), the other one is oriented in a fixed direction (e.g., North, East, South or West). The data was collected for about four hours each day to capture different elevation angles and satellites.

Next, we integrated a similar spinning mechanism into the bottom of a quad copter as shown in Fig. 3. In this experiment, we attached one phone to the spinning ground plate to collect reflected signals while another one is placed upward and placed on the ground unit to collect direct signals. The ground unit was run for about 4 hours, similar to the previous experiment while the UAS was flown at a fixed altitude of 15 m and a constant speed of 5 m/s along several straight paths for about 12 minutes per flight and repeated four times during the 4-hours time period. We repeated the same plan on November 23, 27, 28 in 2021. Reflectivity at various elevation angles are obtained by taking the logarithmic difference between measurements (GNSS carrier-to-noise density ratio C/N_0) on a small UAS and open area as

$$\text{Reflectivity [dB]} = C/N_{01}\text{[dB-Hz]} - C/N_{02}\text{[dB-Hz]} \quad (1)$$

where C/N_{01} is measured in an open area while C/N_{02} is via a small UAS. In the following section, we will provide results from sample data for aforementioned experiments.

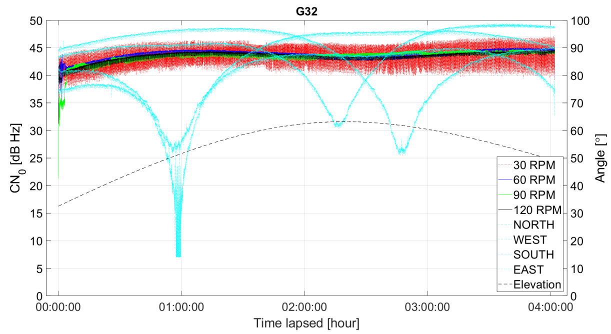

Fig. 4. A sample ground test result from time-series experiments on four different days (October 24, 26, 27 and November 1, 2021).

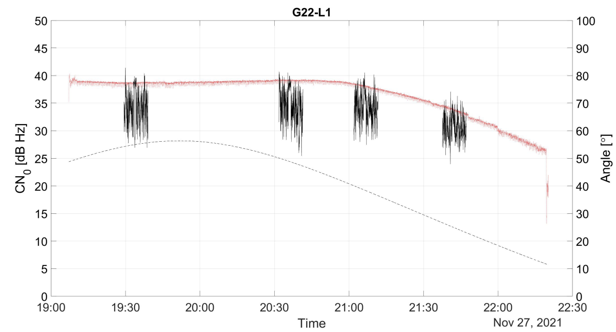

Fig. 5. A sample flight test result from the experiment that took place on November 27, 2021.

3. RESULTS

In the section, we will provide preliminary results about the impact of spinning speed on the received signal as well as the flight tests. Fig. 4 shows the received signal strength (C/N_0) for stationary and spinning phones. The cyan color represents phones that are oriented towards North, East, South, or West. As clearly seen, the received signal has dips at different levels and locations for each orientation. One would expect that such dips would also appear if we orient the phone in different directions. This result is expected and is the main reason for spinning the phone with ground plate. The other colors represent the signal strengths from different rotation speeds. As seen from the same plot, the dips disappear for each rotation, but 30 RPM rotation fluctuates more than the other rotations as it samples the data over half cycle only. The other rotation choices have similar signal levels and variations. While we show the results from Global Positioning System (GPS) L1 Pseudorandom Noise (PRN) Code # 32, we also obtained very similar results for other GNSS satellites. The major implication of this experiment was that we remove the dips of the antenna radiation successfully by rotating the phone more than 60 RPM (i.e., at least one full rotation every second).

Next, we fixed the speed of rotation at 60 RPM. The results from the flight experiment for GPS L1 PRN # 22 are given in Fig. 5. The black colors denote the data collected by the down facing unit on the UAS while the red color represent the data collected upward facing ground unit. The dashed lines denote elevation angles. As expected, the signal strength from the ground unit (that collects the direct signal) does not have dips and exhibits a quite uniform response during the experiment duration which was about four hours. The received signals by the drone units (collects reflected signal) fluctuates since the specular points travel over different land features as the drone flies along a straight path. As we hypothesised, the reflected signal is lower than the direct signal, so the difference signal in Eq. 1 represents reflectivity. However, the reflected signal is occasionally larger than the direct signal. These instances happens when the drone turns from one flight line to another one. Additionally, as the drone flies, the phone is not pointing straight down to the ground due to the pitch angle of the drone. This indicates that the angular dependence of the antenna pattern still needs to be compensated.

4. CONCLUSIONS

Recently, we proposed integration of smartphones into a small UAS to sense water in soil by using reflected GNSS signals. The main limitation of such an approach was the irregular antenna pattern of smartphones. In this paper, we presented a novel approach to eliminate the impact of the built-in antenna on the received signal by spinning the smartphone with its ground plane. We conducted several experiments to demonstrate the feasibility of such an approach. The results are indicated that spinning the phones more than 60 RPM eliminates the dips in the radiation pattern and makes it quite uniform. Additionally, we showed that the reflected signal is lower than the direct signal when we compare the signal strength from the down facing unit attached to the drone with the upward facing unit on the ground. This paper will extend preliminary analysis to other GNSS satellites, L2 frequency band as well as fusing received signals with drone flight data to relate the reflected signals with ground features. Finally, more emphasis will be placed on characterizing the angular correction needed for direct and reflected signal comparisons.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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