UAS-Based Antenna Pattern Measurements and Radar Characterization

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***Abstract*—This paper presents an update of the current in-situ antenna characterization and calibration of a radar system using an Unmanned Aircraft System (UAS) developed by the Advanced Radar Research Center (ARRC) at The University of Oklahoma. A large multirotor platform was customized for long endurance (∼30 minutes), high positioning accuracy (<3 cm), and high stability, and was integrated with a high precision 3-axis gimbal that holds an antenna array and pulse generator-transmitter. The platform was designed to support measurements from 2 GHz to 10 GHz, however, the current setup described in this article includes an S-band array probe of 3x3 elements. The RF probe beamwidth was optimized to minimize reflections from the UAS frame and to provide accurate antenna measurements in flight conditions.**

***Index Terms*—In-situ antenna measurements, UAV, UAS, DGPS, RTK, radar calibration, antenna measurements, dual-polarized radar.**

I. Introduction

In an effort to efficiently utilize the radio-frequency (RF) range, the Spectrum Efficient National Surveillance Radar (SENSR) program is developing the concept of a Multi-function Phased Array Radar (MPAR) network, which attempts to combine the functions of weather surveillance and air-traffic control in a single, phased array radar system [1]. As far as weather surveillance is concerned, There are benefits to using a phased array radar (PAR) for weather surveillance including fast scanning updates, low profile, reconfigurability, adaptability, scalability, relatively lower long-term costs, and high graceful degradation. Characterizing antennas requires specialized indoor or outdoor range facilities that introduce space and cost constraints to testing. However, an antenna characterized in an indoor facility does not necessarily perform identically in an outdoor environment under normal operating conditions. For this reason, calibration of the system is necessary to adjust the performance to acceptable levels. This is particularly true for polarization, which is a function of scan angle in phased arrays and is difficult to predict, in general, based on simulations alone. Therefore, an outdoor installation for characterization is necessary to adequately characterize the system and mitigate the effects of an antenna's external environment. Unfortunately, it is cost prohibitive and impractical to develop such facilities for a network with a large number of radars. Previous work in this area required a wide variety of methods and equipment for calibration of different aspects of a radar system. In weather radars, calibration is commonly performed using a known fixed target as reference, a tethered balloon, or by pointing the radar to zenith. However, in such cases there is usually no control over the measured target, and thus, uncertainty exists. Ideally, complete control of the in-situ measuring instrument would be necessary to accurately characterize the radar system [2].

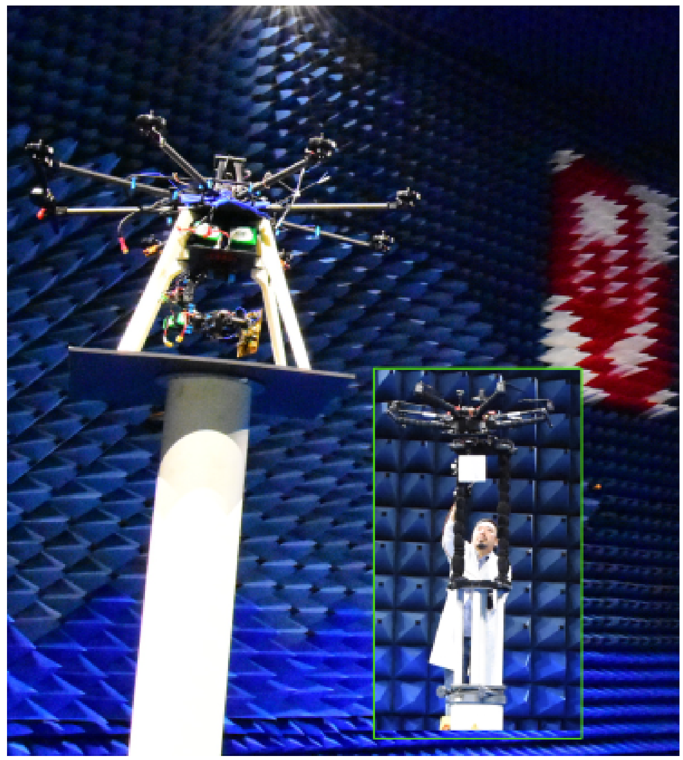

Fig. 1. ARRC UASs units for S-band antenna pattern and radar system characterization. In the left, an octocopter, and in the right, an hexacopter platform during RF test of the antenna array transmitter probe in the far-field range at the Radar Innovations Laboratory (RIL) at The University of Oklahoma.

The rapid development of UASs has enabled cost-effective solutions for prototyping and consumer-grade applications for

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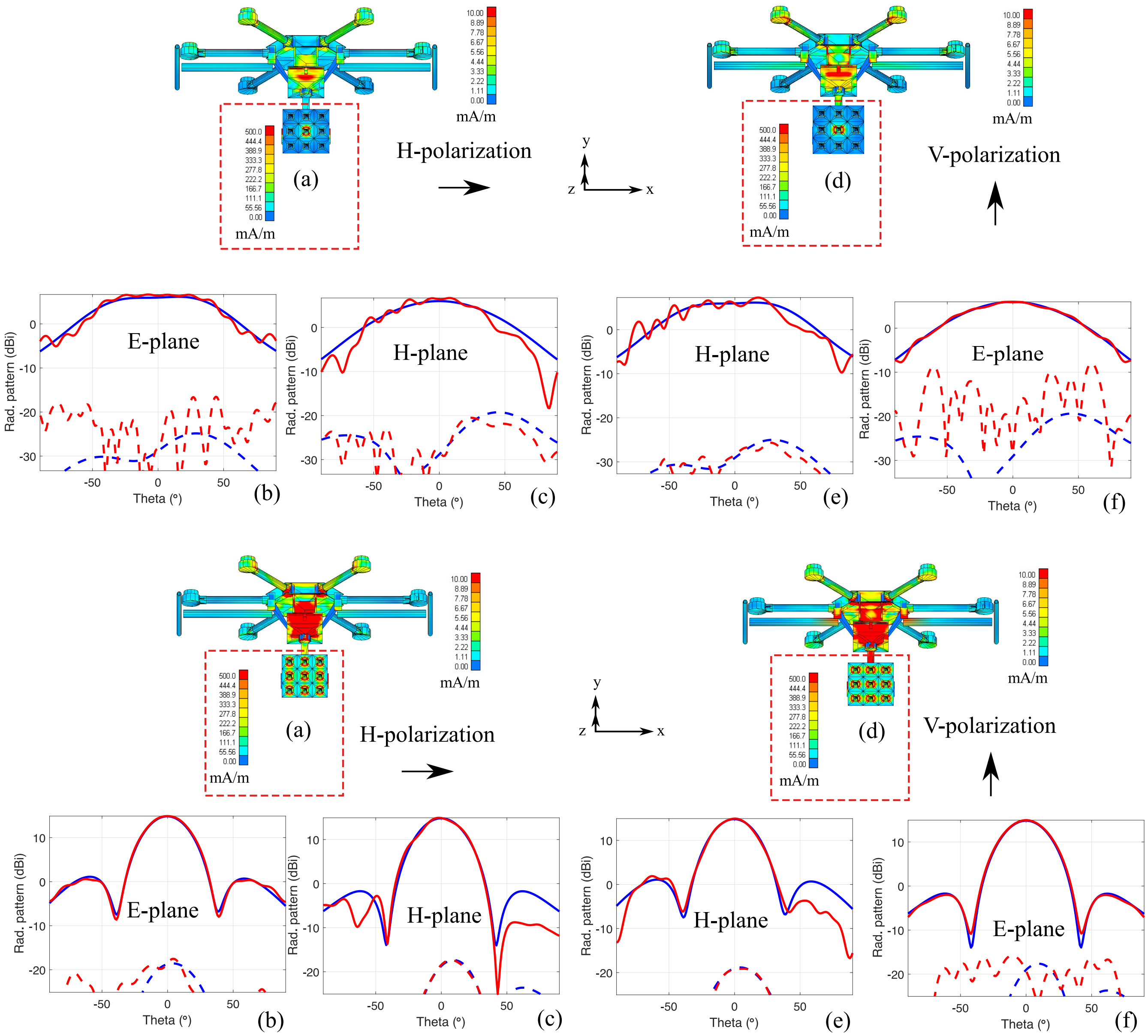

Fig. 2. Effect of the hexacopter UAS structure on the S-band RF probe antenna patterns when the array of 3x3 elements is excited with the central embedded element (top), and when all the elements in the array are excited uniformly (bottom). In both cases, the left, corresponds to a vertically-polarized probe and the right, to a horizontally-polarized probe. In top and bottom: (a,d) Current density on the probe and the UAS structure. (b,f) E-plane antenna patterns with and without the UAV (red and blue, respectively). (c,e) H-plane antenna patterns with and without the UAV (red and blue respectively).

remote sensing. Commercially available aircraft, as well as off-the-shelf components, instruments, and sensors, can be combined to design a UAS customized to meet specific scientific demands. Previous UAS-based antenna measurement efforts include VHF and UHF ranges of the RF spectrum. However, it is especially difficult to characterize weather radars using UASs due to the fact that aircraft stability, misalignment errors, and aiming accuracy are critical in microwave frequencies, where centimetric (or better) precision is essential.

Today, UAS technology combines top quality gyroscopic stabilization, inertial measurement units (IMU), and autonomous flight modes that allow vastly improved aerial stability, which enables high quality 3-D maps, photogrammetry and lidar imagery. High performance flight controllers and a new generation of algorithms for DGPS, such as Real Time Kinematics (RTK) algorithms, improved UAS positioning accuracy by two orders of magnitude (from 2-3 m to 1-4 cm) [3]. New adaptive controllers for multi-rotors allow very stable platforms that provide reliable operation in circumstances where the wind speeds are higher than 40 mph. New generation portable batteries and motors have improved the overall efficiency of drones and have extended their autonomy from standard durations of 15-20 min to more than 30 min. Recent publications show the results of in-situ antenna characterization using small UAS [4]–[7].

For weather radar calibration, the differential reflectivity (Z_{dr}) is a polarimetric variable of crucial importance, used for hydrometeor classification and estimates such as rainfall rate. Consequently, a robust calibration method is needed to characterize and remove Z_{dr} bias in weather radar. The community has agreed on the 0.1 dB standard deviation value as being the ”holy grail” to aim for. No systematic method to consistently attain the standard deviation value has been devised so far [8]–[10]. The most famous and widely used method remains the use of metal spheres tethered to helium balloons, as known targets. Values as low as 0.2 dB have been obtained in [11]. This paper presents an update of the current UAS developments with emphasis on improvements in purity of the RF probe and high position accuracy.

II. Current Progress of Platform Development

The proposed concept consists of a platform capable of carrying a sensor suite that enables several missions for radar applications. The most important missions for the SENSR program, are in-situ antenna measurements and radar characterization and calibration. To perform these two missions, our team developed two UAS platform prototypes capable of supporting a payload to carry a 3-axis gimbal with a mounted RF probe consisting of an array antenna in S-band and a large bandwidth RF synthesizer. The platform also requires additional sensors, such as a lidar for high precision altimetry, and a DGPS system for sub-decimeter position accuracy. Large batteries ensure an operational endurance of up to 35 minutes, which is important for guaranteeing mission completion without interruptions. More details of this concept and initial experimental tests to validate the proposed platform for multi-mission use is presented in [12].

A. *Impact of UAS Structure on the Probe's RF Performance*

Radiation field interaction between the RF probe antenna and various UAS components (such as the frame, propellers, gimbal, batteries, and small metal objects) may impact the RF probe performance and reduce the accuracy of in-situ antenna measurements and radar characterization. Spurious radiation from the UAS platform induces ripples and altered co-polar beam match patterns, and degrades the cross-polarization isolation of the antenna under test (AUT) [13], [14]. To avoid this, and preserve the intrinsic characteristics of the RF probe, a small electrical structure built with materials with low permittivities close to that of air is preferable. Moreover, if the probe has directive properties, it will radiate low amounts of power toward the structure, further minimizing this phenomenon. A trade-off between the RF probe beamwidth, gain roll-off, and position accuracy is required to identify the optimum antenna array size required for the RF probe. RF absorbing materials are also recommended on the areas of the UAS structure that are the most sensitive to scattering and diffracted fields. Since theoretical formulation of the effects of such a phenomenon on the probe's antenna patterns is a formidable task, the most effective approach is to use an electromagnetic modeler/solver capable of simulating such a complex system. WIPL-D is a numerical solver based on the method of moments (MoM) that can simulate antenna systems on arbitrary metallic and dielectric structures quickly and accurately [15]. Spurious radiation from the hexacopter frame is represented in Fig.2. In both cases, we use a WIPL-D EM simulator to represent the patterns of an RF probe when the center element is excited in the array and the other elements are terminated with 50 Ω loads, and also when all elements in the array are equally excited. As was expected, (see Fig. 2) when exciting one single element in the array, the broad beam pattern induces surface currents in the frame that degrade the overall performance of the RF probe, especially the cross-polar patterns. Ripples with amplitude of 3.3 dB and cross-polarization distortion higher than 10 dB are observed when a single element is used as RF probe. To mitigate reflections and diffractions on the UAS, a linear array (column and row) and a planar array of 3x3 elements were simulated. The best results were obtained when all elements in the planar array of 3x3 were excited.

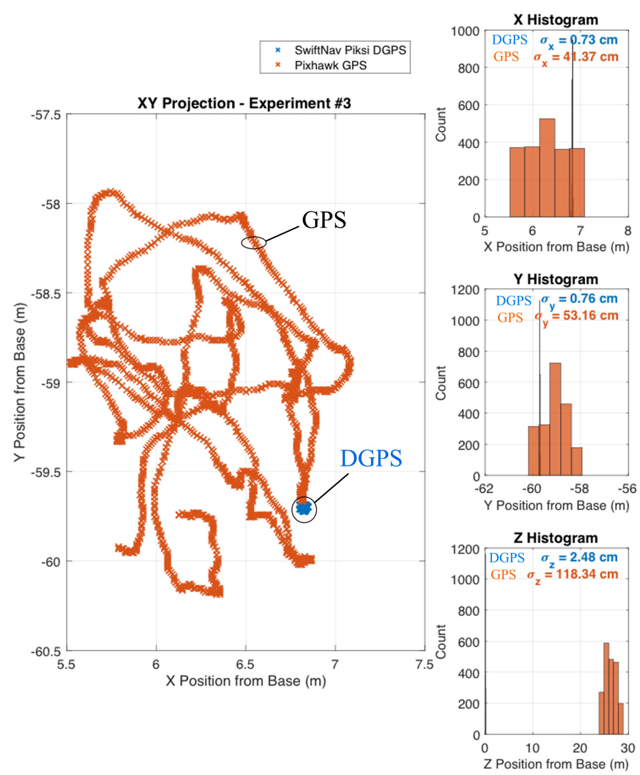

Fig. 3. Measured position accuracy performance using GPS and DGPS for hexacopter UAS prototype

B. *Position Accuracy*

Unlike standard measurement techniques where the position of both the probe and the AUT is either fixed or known (and accounted for in post-processing), and the ground reflections are either controlled or cancelled, the new proposed measurement technique is different. There is a drift between the desired and actual position of the UAS due to instrumental inaccuracies of the GPS, IMU, barometer, and gimbal—, the impact of environmental conditions such as wind, and the effects of the flight control technique. Compensation for position drift, if known accurately, can be made in the measurements. To minimize position errors, differential GPS (DGPS) using a RTK algorithm is proposed. RTK GPS works the same as standard GPS, but with added features to ensure accuracy within a few centimeters. Two GPS receivers are used, the base at an accurate known position on the ground, and the rover located on the vehicle. Using the phase of the satellite signals as well as its own accurate position, the base can use the RTK algorithm to remove the main GPS errors.

The Post-Processing Kinematics (PPK) performance of the Emlid Reach DGPS unit has been tested in stationary operation (i.e., UAS on the ground) at four different locations. These four locations were separated approximately 20 m apart with 900 sample points per set to determine the precision of the DGPS unit. An approximate improvement of two orders of magnitude was achieved when compared to the single GPS position measurements. However, with the Reach module, it was very difficult to obtain the RTK with fixed precision mode flight, so another DGPS unit was suggested. With the SwiftNav Piksi DGPS, RTK, fixed precision mode is more easily and consistently achieved, both on the ground and in-flight. Similar ground tests have been conducted at four different locations to determine the precision of the Piksi DGPS unit installed on the hexacopter UAS calibration project. DGPS in RTK mode shows improvement in performance over the DGPS in PPK-mode. The DGPS in RTK mode obtained position accuracy of about 1 cm in the x-, and y-axes. The precision in the z-axis is under 3 cm for the second set of tests, whereas for the first set of tests it was close to 1 cm. This is presumably due to the lidar being used to aid in altimeter readings in the first set of tests, while the second set of tests might not have been using this device. Fig 3 illustrate measured results of the hexacopter with GPS and DGPS.

III. Conclusions

Progress in the development of a new proposed concept for characterizing antenna patterns and performing radar characterization and calibrations using a UAS platform was presented. A novel UAS platform with new features including a high quality RF probe for high cross-polarization isolation, capacity for a large payload to carry an S-band array probe, extended flight time for up to 35 minutes of use, increased flight stability to operate in windy conditions, high position accuracy ($<$3 cm), and use of open-source software, will substantially increase the quality of results for proposed missions. An RF probe of 9 and 12-element array are considered for the final prototype. [**?**]

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