SARFID on Drone: Drone-based UHF-RFID Tag Localization

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***Abstract*—This paper presents a localization system for objects tagged with UHF-RFID passive tags, where the reader is attached to a drone. The system implements the phase-based SARFID technique to locate static tags with respect to a UHF-RFID reader attached to a commercial drone. The reader antenna trajectory is achieved through a Global Positioning System. The bi-dimensional tag position is estimated with centimeter order accuracy. Only one reader antenna is required, without any reference tag.**

***Keywords*—RFID drone; RFID UAV; UHF-RFID localization; SARFID**

I. INTRODUCTION

Recently, the drone technology received great attention to develop new applications, thanks to its capability to reach dangerous places, huge spaces or not easy accessible by humans. To name just few, drones can be employed for indoor inventory by equipping the barcode technology [1], for industrial inspection, precision agriculture, structural monitoring through an infrared camera [2], or for home delivery [3]. In all these scenarios, the RFID technology can help the drone activities, by implementing both identification [4] and localization features. A drone can be equipped with a RFID reader to locate tags within an indoor or outdoor scenario, or alternatively it can be equipped with an RFID tag to be localized from a grounded RFID system [5].

In the state-of-the-art, a few works exist on the deployment of RFID-based localization system through drones, and typically the amplitude of the tag backscattering signal is exploited [6]-[8]. In [6], a device-free UHF-RFID localization scheme has been proposed to locate an Unmanned Aerial Vehicle (UAV). The method is based on the principle that a metallic object, as the drone, affects the tag detection in terms of Received Signal Strength Indicator (RSSI). Thus, the stationary reader detect the tag RSSIs during the drone flight and determine the group of tags affected by major variations. From the latter group of tags, the UAV position is estimated. In [7] a localization system has been proposed for environmental monitoring through an UAV equipped with a 433 MHz RFID reader. When a tag is detected, the UAV continue to rotate in the area performing RSSI measurements from which the tag distance is estimated by employing an assumed path loss model. Then, by knowledge of the drone position by a Global Navigation by Satellite System (GLONASS or GNSS) receiver, a multilateration algorithm has been applied to locate static tags.

This paper presents a new localization system employing a drone equipped with an UHF-RFID reader to locate tags in outdoor scenarios. The system exploits the SARFID phase-based localization technique (Synthetic Aperture Radar approach for RFID tag localization) [9]-[10], which takes advantage of the relative motion of the reader antenna with respect to the static tags. The experimental setup is realized with commercial hardware, specifically the Colibrì IA-3 drone by IDS [11] and the Impinj Speedway Revolution R420 UHF-RFID reader. The knowledge of the drone trajectory is got from a GNSS receiver on the drone. The RFID system integration on drone is described in Section II. Then the measurement campaign is described in Section III together with the analysis of multiple tags localization performance. Finally some conclusions are drawn in Section IV.

II. RFID READER INTEGRATION ON DRONE

The experimental setup has been realized by integrating the Impinj Speedway Revolution R420 UHF-RFID reader on the drone. The first configuration step requires a wireless pilot of the reader, thus the latter has been equipped with the Wi-Fi module Vonets VAP11G-300 according to the procedure suggested by the reader manufacturer Impinj. Then a mobile phone hotspot has been exploited to realize the wireless connection between the reader and the laptop (Fig. 1).

Besides, a key point to develop the localization system is the drone trajectory knowledge, which is a requirement for the SARFID technique application. For outdoor scenarios this can be easily guaranteed by a Global Positioning System (GPS) receiver, typically available on drone. In particular, the Colibrì drone has been equipped with a Compact Dual Frequency GNSS Board TOPCON B110 [12]. By exploiting a Differential GPS configuration with a Leica GS15 GPS/GLONASS fixed station, the drone position is estimated with a rate equal to 200 ms and an error lower than 2 cm. Such a value will determine a localization error of the same order of magnitude on the tag position estimation.

The drone position is determined with respect to the GNSS module clock which can differ from the reader clock, thus a proper synchronization among them has been realized.

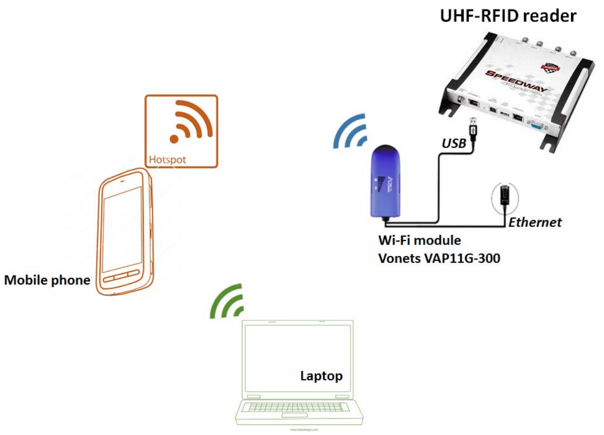

Fig. 1. Scheme of the wireless connection between the laptop and the RFID reader through the mobile phone hotspot.

Fig. 2 depicts the final drone configuration with the GNSS module, the RFID reader and the circularly polarized RFID antenna WANTENNAX005 by C.A.E.N. RFID.

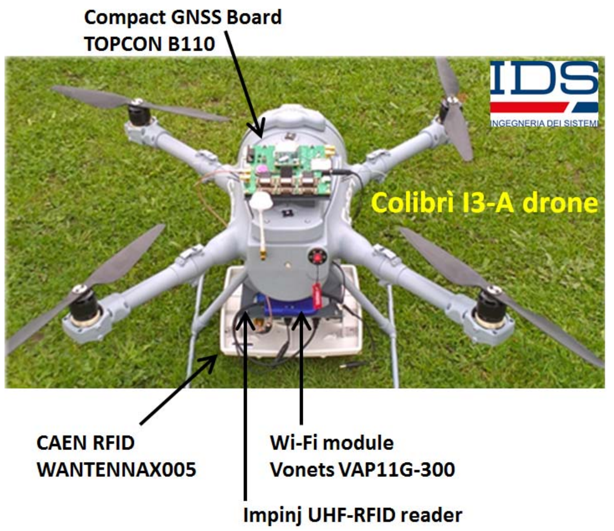

Fig. 2. Colibrì I3-A drone by IDS, equipped with the GNSS module and the UHF-RFID reader and antenna.

III. Localization Performance

A. Measurement Setup

The experimental setup has been deployed in an outdoor scenario by employing a grid of 5×5 tags. Different tags have been employed to verify the SARFID localization capability independently on the tag typology. From the first to the end row, the following typologies have been used: the Alien ALN 9640 (#11001-#11005), the Avery Dennison AD-229 (#29001-#29005), the Alien ALN9654-G (#54001-#54005), the Smartrac Dogbone (#33001-#33005) and the LABID UH106 (#06001-#06005). Tags on odd rows are aligned along the *x*-direction while tags on even rows are along the *y*-direction (Fig. 3). The inter-tag distance is equal to 2 m and the local reference system has been centered on the first Alien ALN9640 tag. RFID data have been acquired at the operating frequency of f_0=865.7 MHz (ETSI Channel 4).

The tag position has been calculated through a fixed GPS/GNSS receiver at the beginning of the measurement campaign, with the aim to evaluate the localization error, namely the system accuracy, after applying the SARFID technique. As for the drone trajectory, the GPS tag positions can be known with a centimeter order accuracy that is reasonable by considering the tag size (of around 10 cm) and the size of the item the tag is attached to.

The pilot drives the drone on the tag grid running a nearby square-wave trajectory in order to detect all tags displayed in the 64 m^2 area (Fig. 4). Along the *x*- and *y*-directions the antenna path width is around 10 m and the drone speed varies between 1 m/s and 2 m/s.

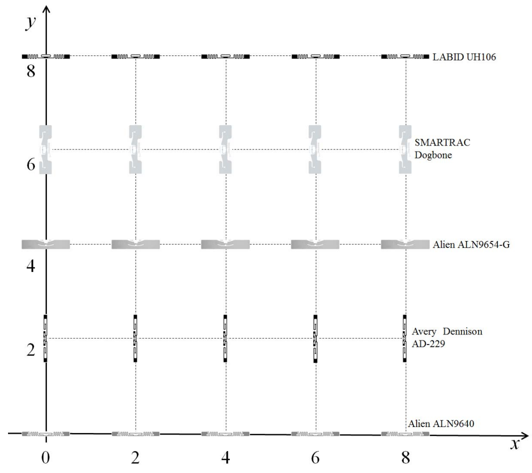

Fig. 3. Grid of 5×5 tags with inter-tag distance equal to 2 m employed for the measurement campaign.

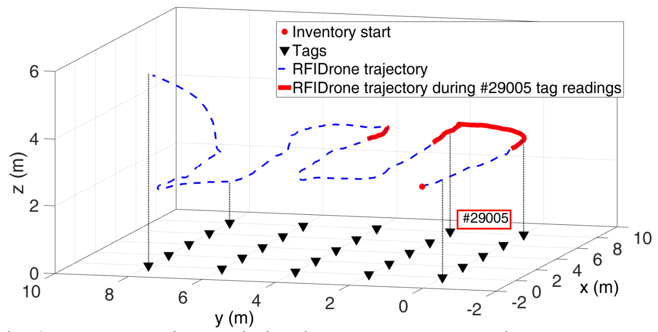

Fig. 4. Drone trajectory during the measurement campaign.

B. SARFID: 1D localization performance

Let us briefly summarized the SARFID localization technique [9]-[10]. When an antenna is moving with respect to a static tag, the phase variations of the reflected signal complex envelope are related to the variation of the relative distance between reader antenna and tag. The SARFID technique exploits the phase-variation history measured at the output of the reader I-Q receiver, by comparing it with nominal phase variations that can be easily constructed if the scenario geometry is known. Indeed, the nominal phase-variation history can be analytically evaluated for a given assumed position of the tag, if reader antenna trajectory is known. Finally, a phase matching operator is applied to determine the nominal history that best fits the measured phase variation history, resembling a (knowledge-based) synthetic array approach. The position associated to the so selected nominal history is chosen as the more likely position of the tag. For more details the reader can refer to [10].

The SARFID technique can be implemented to determine the 1D, 2D or 3D localization of tags, if the reader antenna runs a linear, a planar or a volumetric scan. The localization accuracy is strictly dependent on the path length along each direction with respect to the antenna-tag distance [10].

During the drone scan, each tag is detected in a different path that can be easily determined by intersecting the time of the drone trajectory with the time of the RFID readings. As an example, let us considering the tag #29005: during its detection, the drone trajectory on the *xyz* space is represented in Fig. 4 (thick solid line). The synthetic aperture length (L) along the three reference axes is equal to L_x≈8.46 m, L_y≈2.60 m and L_z≈0.81 m. Since the trajectory variations are mainly along the *x*- and *y*-directions, only the SARFID mono-dimensional and bi-dimensional processing have been investigated through the paper.

The relative phase history employed as input of the SARFID technique is represented in Fig. 5 (solid line) together with the theoretical behavior derived from the knowledge of the tag GPS position. N_r=674 readings are collected with a temporal sampling of around 34 ms. Two distinct curve portions can be observed due to the fact that the drone detect the tag in two different segments of its trajectory (see Fig. 4).

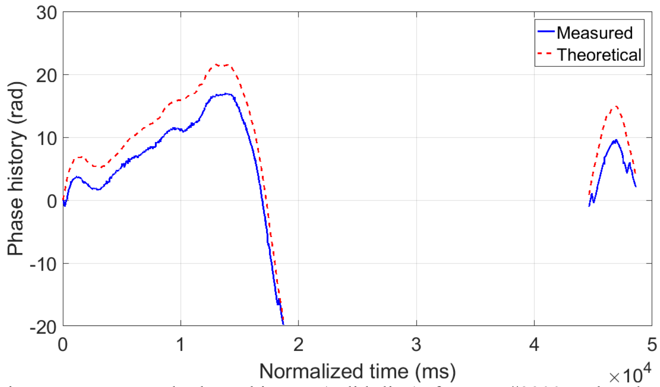

Fig. 5. Measured phase history (solid line) for tag #29005 placed at [x_{tag}, y_{tag}, z_{tag}]=[7.96, 2.03, 0.49] m and theoretical phase history (dashed line) calculating from the tag GPS coordinates.

The results of the SARFID technique with a mono-dimensional processing with respect to each of the *x*- and *y*-coordinates have been represented in Fig. 6 through the matching function output. The peak position represents the estimated tag coordinates $\left(\widehat{x_{tag}}, \widehat{y_{tag}}\right)$ for the tag actual position (x_{tag}, y_{tag}) and the localization errors are equal to $\varepsilon_x = \left|\widehat{x_{tag}} - x_{tag}\right| = 1\ cm$ and $\varepsilon_y = \left|\widehat{y_{tag}} - y_{tag}\right| = 6.1\ cm$, for the two coordinates, respectively. The peak value indicates the similarity between the measured phase history and the theoretical one. Higher the peak, more reliable is the position estimation.

By considering all tags within the scenario, the localization error by performing a mono-dimensional SARFID processing for the two coordinates is represented in Fig. 7, together with the synthetic aperture length.

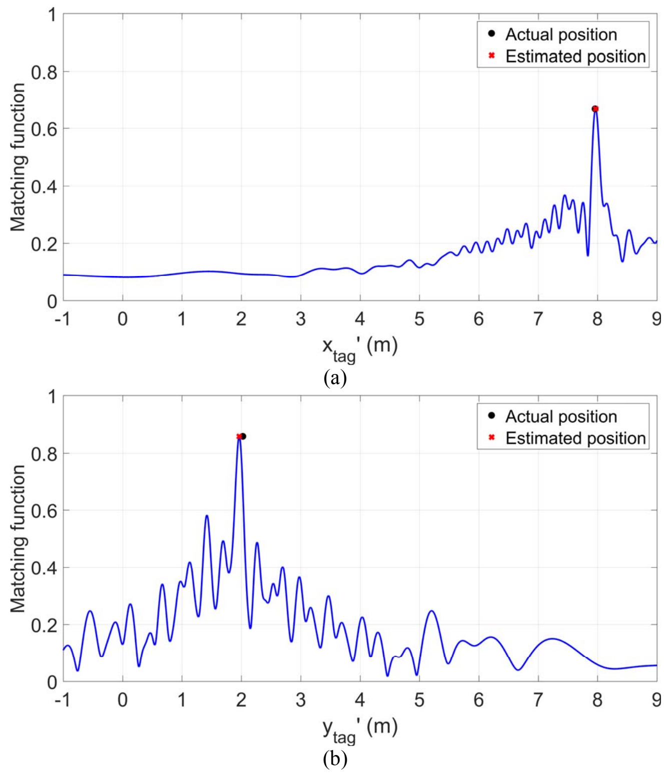

Fig. 6. Matching function of tag #29005 by considering a SARFID mono-dimensional processing with respect to: (a) the *x*-coordinate and (b) the *y*-coordinate. Note that estimated and actual positions are almost overlapped.

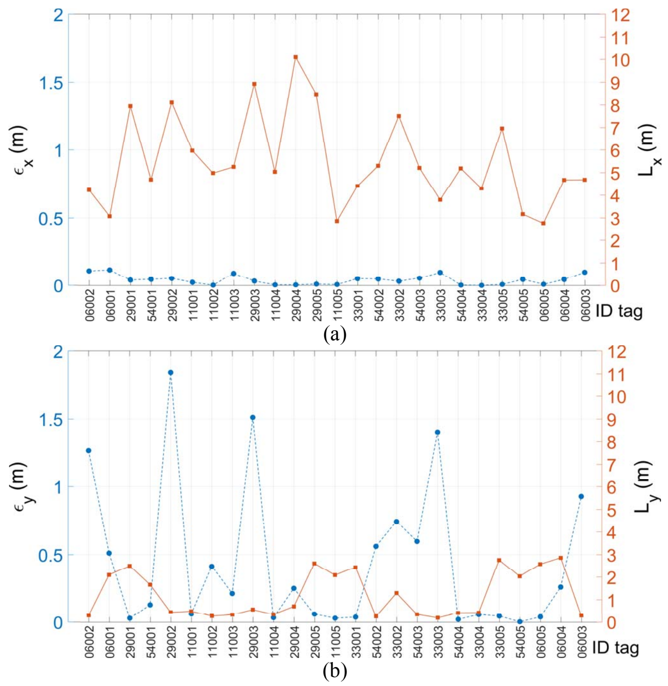

Fig. 7. Localization error (circle marker) and synthetic aperture length (square marker) for the 5×5 tags, by considering a SARFID mono-dimensional processing with respect to: (a) the *x*-coordinate and (b) the *y*-coordinate.

The drone has mainly flown along the x-direction by obtaining a mean value of the synthetic aperture length of $\overline{L_x} = 5.50\ m$ for 25 tags. The mean localization error is equal to $\mu_x = 4.1\ cm$ and the standard deviation is $\sigma_x = 3.6\ cm$. The smaller the synthetic array, the greater the error, as it results for the other coordinate. In particular, the mean synthetic aperture length is $\overline{L_y} = 1.20\ m$ with a consequent worse localization accuracy: $\varepsilon_y = 44.2\ cm$ and $\sigma_y = 54.4\ cm$.

C. *SARFID: 2D localization performance*

The SARFID technique can also be applied with a bi-dimensional processing, trying to simultaneously estimate both the x- and y-coordinates. The 2D matching function for the tag #29005 is represented in Fig. 8.

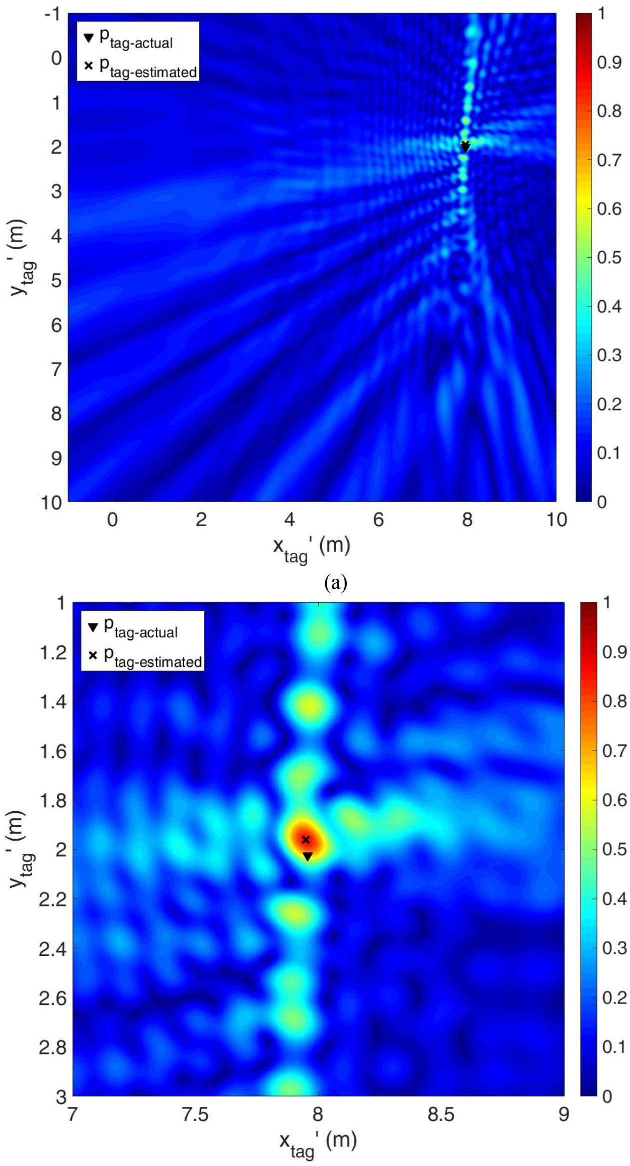

Fig. 8. (a) 2D matching function of tag #29005 by considering a SARFID bi-dimensional processing and (b) zoom around the peak. Note that estimated and actual positions are almost overlapped.

Only a single distinct peak appears, showing that the tag position is estimated without ambiguity. The corresponding estimated tag position is equal to $\left[\widehat{x_{tag}}, \widehat{y_{tag}}\right] = [7.95,\ 1.96]\ m$ while the actual position is $\left[x_{tag}, y_{tag}\right] = [7.96,\ 2.03]\ m$, by showing a centimeter order accuracy (Fig. 8b).

The localization error for all 25 tags is represented in Fig. 9, when comparing the 1D and the 2D SARFID processing.

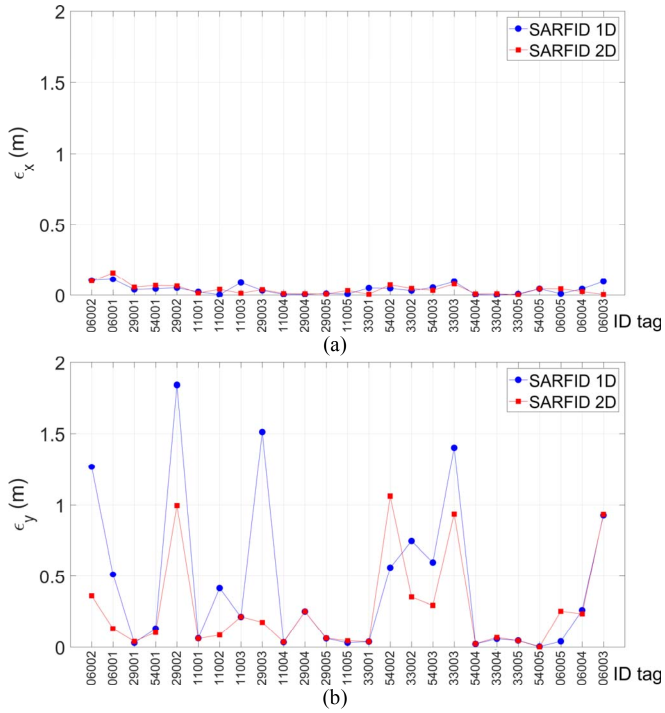

Fig. 9. Localization error by applying a 1D (circle marker) or a 2D (square marker) SARFID processing for the 5×5 tags, for (a) the x-coordinate and (b) the y-coordinate.

The 2D processing allows to improve localization accuracy (mean value) and precision (standard deviation). For the x-coordinate, the mean value and standard deviation of the localization error is equal to $\left[\mu_x, \sigma_x\right] = [3.9,\ 3.8]\ m$. As for the y-coordinate, a significant improvement can be observed with respect to results given in Sect. III.B: $\left[\mu_y, \sigma_y\right] = [27,\ 33.3]\ m$. The measured performance is summarized in Table I.

It is worth noting that in real applications such errors are acceptable when compared with the tag size (of around 10 cm) and the size of the item the tag is attached to (which is greater than the tag itself). Then, we can conclude that the proposed system can have some potentials in real life applications.

TABLE I – LOCALIZATION PERFORMANCE IN TERMS OF ACCURACY AND PRECISION OF THE SARFID TECHNIQUE, WHEN APPLYING EITHER A 1D OR A 2D PROCESSING.

	μ_x (cm)	σ_x (cm)	μ_y (cm)	σ_y (cm)
1D	4.1	3.6	44.2	54.4
2D	3.9	3.8	27.0	33.3

IV. Conclusion

The performance of the phase-based SARFID localization technique has been presented in this paper when the UHF-RFID reader is attached to a drone and static tags must be localized. The UHF-RFID reader has been installed on board of a commercial Colibrì I3-A drone by IDS, together with a circularly polarized antenna. The reader has been driven by a grounded console thanks to a wireless pilot exploiting a Wi-Fi connection. A GPS receiver measures the drone trajectory with the precision and timing required from the SARFID technique.

The bi-dimensional tag position is estimated with centimeter order accuracy in a multiple tags scenario, independently on the tag typology and orientation. Besides, it is worth noting that the SARFID technique works with almost arbitrary drone trajectories, and the drone speed is not required to be constant.

The proposed system requires one reader antenna only, as trilateration procedures are avoided. Moreover, reference tags (anchors) are not required as well. Finally, it can be easily implemented as commercial reader and tags compliant with EPC C1 GEN2 protocols are used.

It is worth noting that the technique can also be applied in indoor scenarios or with Unmanned Grounded Vehicle (UGV). The expected tag localization performance is of the same order of that achieved with a drone, as long as the mobile unit trajectory is known with a satisfactory precision.

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