Short-range passive radar for small private airports surveillance

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***Abstract*— This paper investigate the effectiveness of a passive radar for enhancing the security level in small airports and private runways. Specifically WiFi transmissions are parasitically exploited to perform detection and localization of non-cooperative targets that can be occupying the runway and the surrounding areas. Targets of interest include light/ultralight aircrafts, vehicles, people and even animals that may intrude onto the runways either intentionally or accidentally. The experimental results obtained by means of an experimental setup developed at SAPIENZA University of Rome prove the successful applicability of the proposed approach for small airports surveillance.**

Keywords—WiFi-based passive radar, airfield surveillance.

I. INTRODUCTION

Nowadays exist a huge number of small, privately owned and unlicensed airfields around the world. Private aircraft owners mainly use these "airports" for recreational, single-person or private flights for small groups and training flight purposes. In addition, residential airparks have proliferated in recent years, especially in the US, Canada, and South Africa. A residential airpark, or "fly-in community", features common airstrips where homes with attached hangars allow owners to taxi from their hangar to a shared runway. In many cases, roads are dual-use for both, cars and planes [1].

Typically, ultralight airfields, small private runways, and even airparks, are usually devoid of conventional technologies adopted to guarantee safety and security in large aerodromes, there including navigation aids, signs and lighting. The use of the runways is usually limited to the daylight hours and mostly controlled by dedicated operators equipped with radio transceivers in the HF/VHF band to communicate with the pilots of the aircrafts. These are expected to be cooperative, expert, and well-intentioned users, and to adhere to basic procedures during landing/taking off, taxiing, etc. The operator visually verifies that the runway is empty before authorizing an interested user to occupy it.

Depending on the length of the runways and visibility conditions, several operators might be required to monitor the whole area of interest in order to avoid runway incursions by other aircrafts, vehicles, people, and even animals. In this regard, it is worth mentioning that many of the considered "small airports" are rarely enclosed in a monitored perimeter (e.g. barrier, fencing, etc.) and the edges between runways and taxiways are not clearly indicated. Therefore, it is possible that vehicles or beings intrude onto the runways either intentionally or accidentally. In addition, it would be desirable to monitor the airstrips and neighboring zones also when they are not being used by conventional users (i.e. night-hours, closing times, etc.) in order to avoid an illicit use by ill-intentioned persons. Obviously, the probability of accidents could be significantly reduced if an automatic control is implemented on the activities that occur on the runway and in neighboring zones.

In such scenarios, it would be of great potential interest the possibility to employ low-cost, compact, non-intrusive, and non-transmitting sensors as a way to improve safety and security with limited impact on the airstrips users. Specifically the opportunistic exploitation of transmissions for networking (WiFi, WiMAX, LTE, etc.) is especially attractive since they have been proliferating at a very rapid rate for both commercial and private use and nowadays represent a widely accessible source of opportunity [2]-[6].

Among them, the IEEE 802.11 Standard based (WiFi) transmissions seem to be an appropriate choice in the considered scenarios. Basically, even though they do not feature real terminals, airstrips owners eventually began to offer services and facilities to its users. These typically include the WiFi connection that sometimes is also adopted for pre-flight briefing. Based on the passive radar (PR) principle, the same WiFi access point might be exploited to provide the required radar surveillance capability in the area of interest.

The possibility to exploit such a ubiquitous and easily accessible source has been shown to be an appropriate choice for the detection, localization and imaging of vehicles and human beings within short ranges using the passive radar principle [7]-[10]. Moreover, the feasibility of uncooperatively and covertly detecting people through the walls has been investigated in [11].

In this paper, the potential exploitation of WiFi-based PR systems is investigated with reference to a real-world civil application. In particular, we consider the monitoring application of small private airstrips or airfields. With this terminology we refer to open areas designated for the taking-off and landing of small aircrafts, but which, unlike an airport, have generally short and possibly unpaved runways and do not necessarily have terminals. We report the results obtained in a test campaign performed in a small private airfield for light/ultralight airplanes. Aircrafts and people have been employed as targets of opportunity to simulate different operative conditions of interest. The results obtained with the conceived sensor support the practical applicability of the WiFi-based passive radar concept for improving safety and security of small private airfields.

The paper is organized as follows. Section II illustrate the performed test campaign, the receiver architecture and the signal processing scheme adopted for the results reported in this paper. The results obtained with different experimental tests are reported in Section III. Finally, our conclusions are drawn in Section IV.

II. ACQUISITION CAMPAIGN AND WIFI-BASED PR SET-UP

In this paper we report the results obtained in the test campaign performed in a small airfield named "Aviosuperficie Monti della Tolfa" [12] located in Santa Severa (about 60km North of Rome). Fig. 1 reports an aerial view of the airfield area. The airfield is only used for recreational and training flight purposes. It features a single runway, 520 meters long and 20 meters wide, with a grass surface. Depending on wind direction, take-offs and landings are performed with heading 120° or 300° w.r.t. North.

A. *WiFi-based PR receiver architecture*

The considered data set has been collected by means of the experimental WiFi-based PR receiver sketched in Fig. 2, [13].

A commercial WiFi access point (D-Link DAP 1160) is used as transmitter of opportunity. Its output is connected to the transmitting antenna while a directional coupler is used to send a -20 dB copy of the transmitted signal (the reference signal) to the first rx channel of the four-channel PR receiver. The router was configured to transmit in channel 7 of the WiFi band (2442 MHz). It was set up to roam for connected devices emitting a regular Beacon signal exploiting a DSSS modulation at 3 ms intervals. Other two rx channels are connected to commercial WiFi panel antennas (sizes 33x9.3x2.07 cm) to collect the surveillance signals; the employed antennas are characterized by a gain of 12 dBi, a front-to-back ratio of 15 dB and beamwidths equal to about 80° and 23° on the horizontal and the vertical plane, respectively. The surveillance antennas were mounted at a height of about 1.6 meters from ground, about 40 cm below the transmitting antenna, in a quasi-monostatic configuration (see Fig. 2), and they were pointed at 345° w.r.t. North. Moreover, they were displaced in the horizontal direction by 12 cm, which gives a 45° ambiguity for the target Direction of Arrival (DoA) estimation, based on an interferometric approach.

The system architecture is based on the homodyne receiver scheme (see dashed line in Fig. 2). After an amplification stage (low noise amplifier with gain of 15 dB and noise figure of 0.8 dB), the signals collected at the different receiving channels are down-converted from RF to BB by an I&Q quadrature demodulator that provides to the A/D converter the signals splitted into I and Q paths. In particular, the I&Q demodulators are simultaneously fed by the same local oscillator (LO) signal properly distributed by a four-way splitter. Then the A/D conversion is performed by means of the X3-10M data-capture (by Innovative Integration) with sampling frequency of 22 MHz.

Fig. 1. Scenarios of potential interest in small private airfield monitoring application.

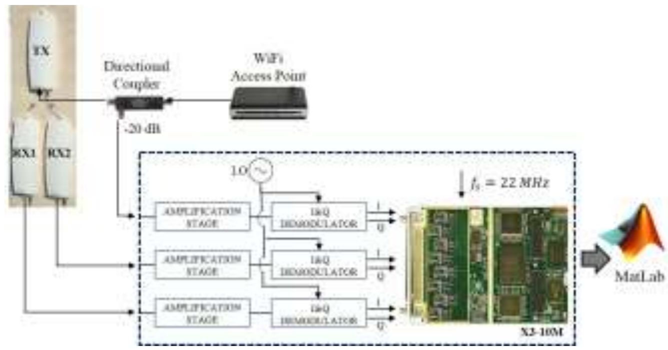

Fig. 2. WiFi-based PR receiver.

This is an XMC IO module featuring eight simultaneously sampled 16-bit, 25 MSPS A/D channels designed for high speed data acquisition applications. Finally, the acquired data are stored for off-line processing.

B. *WiFi-based PR processing scheme*

The WiFi-based PR processing scheme presented in [7],[10] is applied against the surveillance signals. In particular, the removal of undesired contributions is performed with the sliding version of the extensive cancellation algorithm (ECA-S) [14] over a range of 600 m with a batch duration equal to 0.2 s whereas the filter update rate is equal to the beacon emission rate of the exploited access point. A Coherent Processing Interval (CPI) of 0.3 s is then used to evaluate the bistatic range-velocity map over consecutive portions of the acquired signals with a fixed displacement of 0.1 s and target detection is performed by resorting to a standard cell-average CFAR threshold with probability of false alarm equal to 10^{-4}. Then, a two-out-of-two detection criterion is adopted for the two surveillance channels which allows to collect a set of bistatic range and Doppler frequency measurements and to reduce the number of false alarms. As an example, for the case of an test with two targets which will be shown in the next section (Fig. 5), in Fig. 3 are reported in 'x' markers all the plot collected over the whole acquisition time. In order to reduce the false alarms while yielding more accurate range/velocity measurements, a conventional Kalman tracking algorithm over the bistatic range/velocity plane has been applied. Specifically, in Fig. 3 the sequence of green and blue dotted markers represents the first and the second formed tracks, respectively. We observe that the above processing scheme allows to continuously detected and accurately tracked both targets although they have different

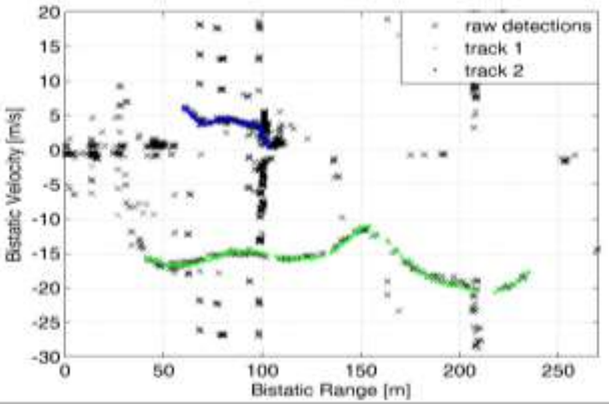

Fig. 3. Detection over the Range-velocity plane for the test in Fig. 5.

velocities. Finally, the phase difference between the two receivers measured at the target detection point is exploited to obtain the target DOA estimation. In fact, target 2D localization in local Cartesian coordinates can be obtained by exploiting the range and DOA measurements provided by the two horizontally displaced surveillance antennas [8].

Several tests of about 20 s have been performed and some examples are reported in the following section.

III. EXPERIMENTAL RESULTS

The first two tests employed a small aircraft as a cooperative target [Fig. 4(a)] equipped with a GPS receiver that continuously recorded its position. The localization results are reported in Fig. 4(b)-(c) where is also reported the main beam angular coverage of the PR antennas in yellow.

In the first experiment [Fig. 4(b)], the aircraft moved on the runway just after landing travelling a distance of about 75 meters away from the receiver. In the second experiment [Fig. 4(c)], the same aircraft moved toward the taxiway from left to right. In both cases, we observe a good agreement with the available ground-truth and targets positions are estimated with good accuracy at least when they are included in the receiver antennas beamwidth.

The third test was performed against two targets taken during a typical operative condition of the airfield. Specifically, a small aircraft, after leaving the hangar, was moving toward the taxiway (see the aircraft on the ground on the left side of Fig. 5(a)). Contemporaneously, an ultralight aircraft, a powered paraglider, was flying over the runway involved in a 'touch and go' landing maneuver. Fig. 5(b) shows the PR localization results; in particular, the same colors of Fig. 3 are used to identify the two tracks once converted in Cartesian coordinate.

As expected, in all cases, the target localization accuracy rapidly degrades as the aircraft gets far away from the PR receiver; basically this is due to the decrease in the target echo power level and to the widening of the uncertainty x-y area caused by a given DoA error. However, the results obtained with the adopted set-up show that the conceived system could be effective in monitoring aircraft activities occurring on and in the proximity of the runway in order to avoid accidents due to intentional/unintentional runway incursions.

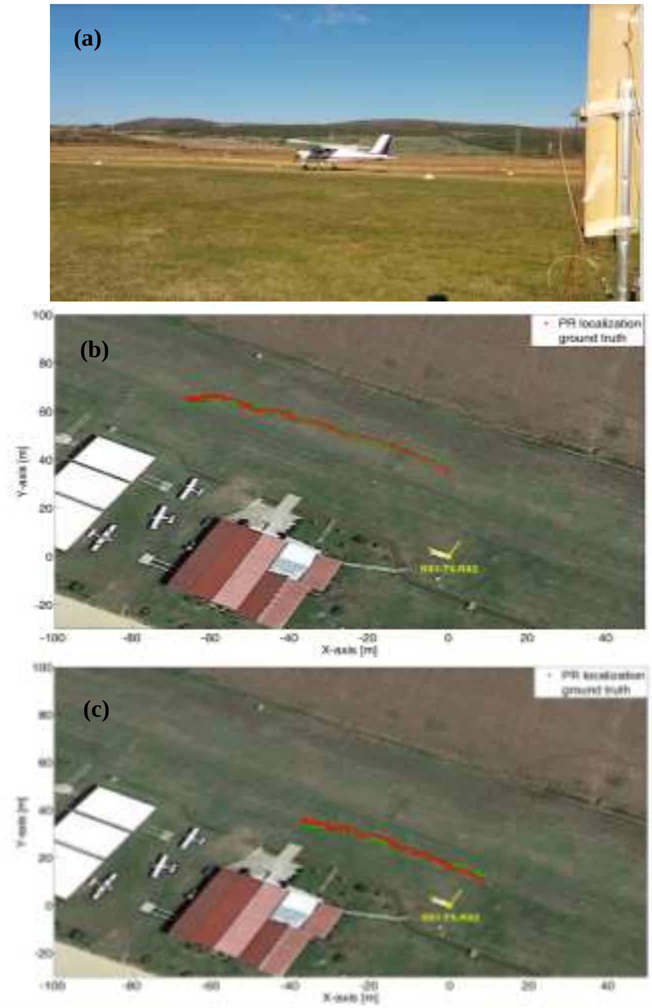

Fig. 4. Test against a cooperative aircraft: (a) picture of the performed test; (b)–(c) PR results compared to the available ground-truth for a landing aircraft and for an aircraft near the runway, respectively.

Moreover, in typical operative conditions, many people might be walking around different airfield areas. Therefore, aiming at improving safety and security in such scenarios, the capability to reliably detect, localize and track human targets might be crucial.

This possibility is proved in this last reported test, where the PR sensor is operated against three people walking in the proximity of the airfield facilities (i.e. club-house, restaurant, etc.) along different trajectories [see Fig. 6(a)]. The PR results are reported in Fig. 6(b) where different colors are used to indicate different tracks. We note that the sensor is able to correctly identify and localize all the targets moving in the considered area. Moreover, for illustration purposes, ideal boundaries have been defined between an allowed area (close to the airfield facilities) and a forbidden area (adjacent to the runway) and the red color has been used for the tracks of the targets crossing the boundaries. Notice that the same approach can be exploited to prevent runway incursions by ill-intentioned people and wild animals living in neighboring areas.

It should be noted that when there is a high concentration of targets moving in the surveyed area, the system could have some limitations because targets that move very close each other are

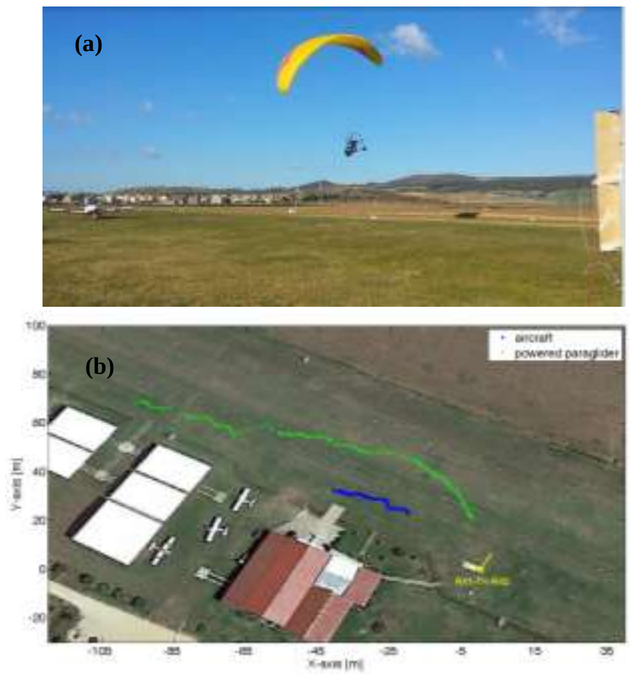

Fig. 5. Test against two maneuvering aircrafts: (a) picture of the performed test; (b) PR results compared to the available ground-truth.

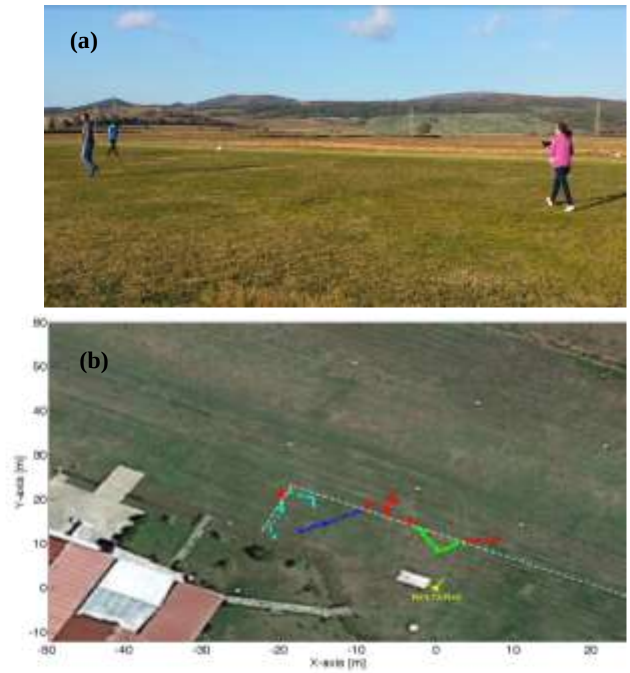

Fig. 6. Test against human targets: (a) picture of the performed test; (b) PR results employed for the security exercise.

not resolved neither in range nor in Doppler. If this is the case, Inverse Synthetic Aperture Radar (ISAR) techniques can be applied to improve the resolution of the sensor in cross-range dimension as shown in [9]-[10].

IV. CONCLUSIONS

In this paper we have investigate the effectiveness of a passive radar for enhancing the security level in small airports and private runways. Specifically a WiFi-based PR developed at SAPIENZA University of Rome has been exploited to perform detection and localization of non-cooperative targets that can be occupying the runway and the surrounding areas. The experimental tests performed in a small private airfield for light/ultralight airplanes have shown that the system is able to correctly detect and accurately track small and ultralight aircrafts and people. The results prove the effective applicability of the proposed system for small airports surveillance.

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