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Passive UHF-RFID narrowband phase-based indoor localization

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***Abstract*—This document aims at summarizing the most recent research activity in the field of UHF-RFID (865-868 MHz) narrowband phase-based indoor localization of our laboratory. Narrowband phase-based localization has many issues to solve, but gives better results than the localization based on the received signal strenght. In this context, we developed, tested and validated a Synthetic Aperture Radar UHF-RFID processing method for passive tag localization. Many measurement campaigns were conducted: the method effectiveness was validated on a conveyor belt, on a robotic arm, on a commercial drone, and on a robot, achieving a decimeter-order accuracy. Recent research trends involves the development of a Neural Network classification approach to determine the moving direction of tagged goods through a RFID gate, and mobile node tracking algorithms based on UHF-RFID technology. The latter represents a challenging problem, which can be solved by adopting sensor-fusion techniques.**

***Index Terms*—RFID, localization, UGV, UAV, tracking, sensor-fusion.**

I. Introduction

The passive UHF-RFID technology (865-868 MHz) has gained more attention in the last years due to its low cost and to the advantages that can bring in the fields of logistic, retailing, warehouse management and smart cities [1]. In this context, the knowledge of the position of the good can be profitably used to improve many services. In particular, it is possible to locate both the RFID tag or RFID interrogating antenna. The information about the distance between the antenna and the tag can be measured in two ways: the first one is to measure the RSSI (*Received Signal Strength Indicator*) parameter, which is related to the received signal strength; the second, is to measure the phase of the backscattering signal by exploiting the digital samples of the received signal [2]. Tipically, the RSSI-based localization gives rougher performance than phase-based localization in indoor environments, due to the multipath effect on the propagation channel and to the dependance of the RSSI parameter on the tag properties. However, since there is no local oscillator inside the tag and the *modulated backscattering* mechanism is intrinsically coherent, phase-based localization methods can be implemeted only for passive RFID tags, which have a limited reading range (8-10 m). Phase-based methods typically exploit the Phase Difference of Arrival (PDOA) [2] of the tag backscattered signal to avoid calibration procedures. The Time Domain (TD-) PDOA method allows to estimate the radial speed of moving tags through phase measurements at different time instants. This solution is robust in rich multipath scenarios, but a fine tag localization cannot be performed. The Frequency Domain (FD-) PDOA method exploits the phase measurements at two or more frequencies to estimate the tag distance. It can be applied for both moving and stationary tags being similar to the Frequency Modulation (FM) continuous-wave (CW) radar. However, such a technique suffers from the limited bandwidth of RFID systems, especially in Europe (ETSI band 865-868 MHz). With the Spatial Domain (SD-)PDOA method, the Direction-of-Arrival (DoA) of the tag signal can be measured by employing two or more antennas. As a result, the tag position can be determined from multiple distance/angle estimates, by applying multilateration or triangulation. Among the SD-PDOA techniques, methods exist which are based on the Synthetic Aperture Radar (SAR) [3] approach with a single moving reader antenna creating a virtual array. The antenna can be moved through a conveyor belt, a robotic arm, an Unmanned Aerial Vehicle (UAV) or ad Unmanned Grounded Vehicle (UGV). The main requirement for the application of this method is the knowledge of the reader antenna trajectory. The lower the measurement uncertainty of a given trajectory is, the smaller the tag position measurement uncertainty becomes.

II. Research activity

A. SARFID method validation acitivities

SARFID [3] is a patented RFID tag localization method based on the SAR principle developed by the Department of Information Engineering (University of Pisa). Firstly, a validation of the SARFID method concerning the 1D localization was performed by exploiting a conveyor belt [3] and a robotic arm [4]. Then, an outdoor scenario where a drone was carrying a commercial UHF-RFID reader and an antenna were employed to verify the 2D localization performance of the method [5] (Fig. 1). In order to apply the syntethic aperture processing, the position of the drone during its path was acquired through a DGPS (Differential GPS) receiver.

A second scenario was built in collaboration with the TeCIP Institute [6], and it included an RFID reader and two antennas placed at different heights carried by a robot (Fig. 2). The position of the robot was measured through a SLAM algorithm (indeed, the robot had several sensors on board such as encoders, sonars and a laser range finder). We decided to put two antennas at different heights on the robot to investigate if it could be possible to perform a centimeter accuracy 3D

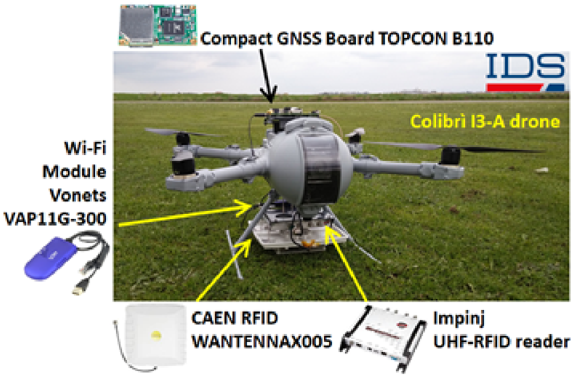

Fig. 1. Drone carrying a commercial UHF-RFID reader and its antenna to verify the 2D localization performance of the SARFID method in [5].

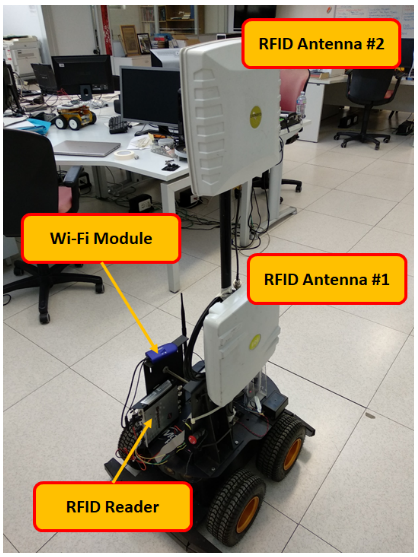

Fig. 2. Robot carrying a commercial UHF-RFID reader and two antennas to verify the 3D localization performance of the SARFID method in [6] and [8].

tag localization [7], which is difficult to achieve if the antenna cannot move vertically. To extend the SARFID method from the 2D and the multiantenna 3D case, several algorithms were investigated (in particular an interferometric radar approach with a genetic optimization algorithm). A third scenario was similar to the second one, but the antenna and the reader were carried by a robotic wheeled walker [8] (Fig. 3). In this case, the antenna trajectory was measured by an infrared calibrated camera system. The aims of this third scenario were: (i) to investigate the effect of the partial knowledge of the phase center of the antenna (which is also modified by the presence of the walker itself) on phase-based radio-localization algorithms; (ii) to develop a tracking algorithm for mobile nodes by exlploiting RFID technology.

B. Mobile node tracking with passive UHF-RFID technology

The development of a tracking algorithm can be propaedeutic for *iRead4.0*, a project funded by Regione Toscana under the POR FESR 2014-2020 program which our research laboratory is currently working on. The aim of the project is to develop a low-cost integrated and autonomous Cyber Physical System for the monitoring and management of goods and forklifts in large high-rotation index warehouses. In order to solve many logistic problems that may occur in large warehouses, we proposed to employ the RFID technology. In particular, one of the project goals is to localize the forklift inside a big area with sub-meter accuracy. We proposed to equip the forklift with a UHF-RFID reader and an antenna, and to deploy several passive reference RFID tags on the warehouse ceiling with as low spatial density as possible. The tags act as anchors for a mobile node tracking algorithm based on a sensor-fusion procedure, which combines the phase data samples gathered from the RFID tags and the data acquired by a set of kinematic sensors placed on the forklift. Differently from traditional tracking algorithms, the phase data are processed through a Synthetic Aperture Radar approach, allowing to solve the problem of phase periodicity and avoiding long calibration procedures. Moreover, the *Aurora* project, funded by the University of Pisa, aims at developing a sensor-fusion tracking algorithm for mobile nodes based on RFID technology oriented to infrastructure minimization.

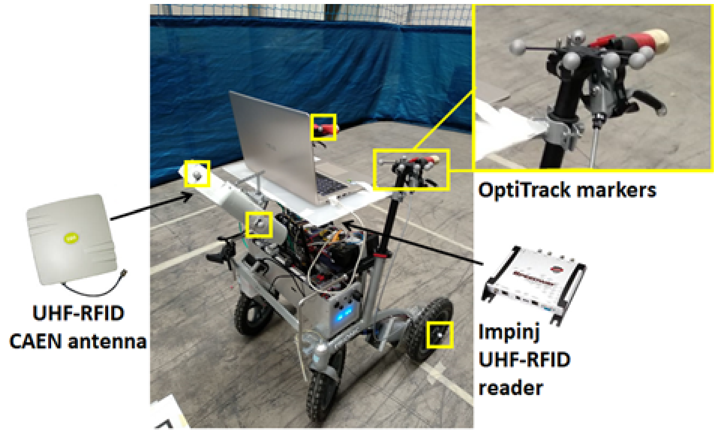

Fig. 3. Wheeled walker carrying a commercial UHF-RFID reader and its antenna employed in [8].

C. Classification in presence of UHF-RFID Gate

In the iRead4.0 project context, there is also the need to deploy some gates capable to discriminate the moving direction of the crossing goods in strategic places. We are currently investigating on a new solution based on RFID technology, which also makes use of some Machine Learning algorithms like Recurrent Neural Networks RNN.

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