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Hand-Held Radar for People Tracking in Indoor Scenarios

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Abstract

In this paper, a portable RFID reader operating at the frequency of 2.45 GHz is described: it exploits the Monopulse RADAR technique with the added capability of electronic beam-steering. This architecture has already demonstrated its effectiveness in multiple tags accurate localization in harsh electromagnetic indoor environments: here, the additional capability of simultaneous tracking of multiple dynamic tagged entities (objects or people) is presented. The proposed system is able to precisely detect the angular position of the tags; a simple algorithm based on the received signal strength allows to fast estimate the distance of the tags from the reader with satisfying accuracy. Thanks to this simple and light reader, long-term people habits and ambient occupancy in typical indoor scenarios can be accurately monitored in almost real time.

1. Introduction

Over the last few years, with the growing availability of low-cost and low-power wireless sensor networks (WSN), there has been an ever-increasing trend to include innovative wireless technologies in living spaces in order to create Smart Spaces and allow different Internet of Things (IoT) operations.
In such contexts, the RFID technologies play an essential role: the remote identification of distributed objects is a key issue and a tough task in a wide number of application fields, such as smart homes, fitness and structural health monitoring. Moreover, in the last decades, the average age of the population is rising and, as a consequence, also the number of retired people is significantly increasing and their monitoring to detect as soon as possible any kind of disease or issue related to the age is becoming a matter of urgency; moreover, it's demonstrated that the early detection of disorders such as Alzheimer's disease, major depression or other types of senile dementia, can be accomplished by analyzing the movements and the behavior of high-risk patients [1].
In this work we show how this operation can be performed by a simple and light-weight reader operating at 2.45 GHz. This reader exploits the Received Signal Strength Indicator (RSSI) from cooperative RFID tags, i.e., the tags worn by the patients are, at this stage, active tags equipped with the same radio (TI's CC2500) of the reader. Many researches have been carried involving the RSSI information of cooperative tags: most of them involve fingerprints strategies [2], for which a sort of look-up table is filled with a high number of RSSI measurements in order to counteract the RSSI strong dependence on the environment and instability. Of course, these approaches need for heavy data collection campaigns.
The proposed reader is able to strongly reduce the needed amount of stored data. This is possible thanks to a slight increased hardware complexity with respect to commercial readers: the combined exploitation of the RADAR-Monopulse and the array beam-steering technologies [3] allows to limit the multi-path effect and to guarantee good localization accuracy of moving tags, despite its simplicity.

2. Reader Architecture

The reader has been presented for the first time in [3], for the detection of fixed tags in hostile electromagnetic environments. For completeness, a brief description of the hardware architecture is proposed in this paragraph. Fig. 1 shows the photo of the prototype.

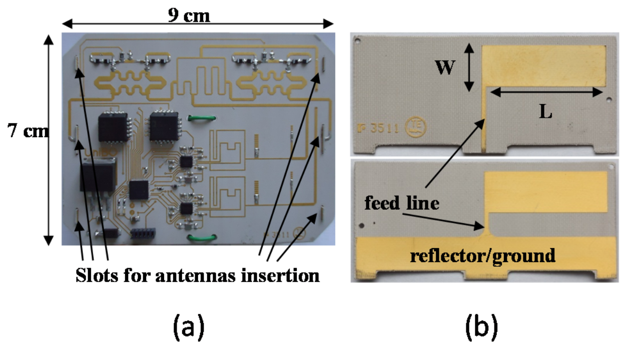

Figure 1. Reader prototype: (a) circuit back view; (b) antenna layout.

Through the electromagnetic/circuital design of a reflection-type phase shifter [4] (Fig. 1(a)), given by a meandered branch-line coupler whose inner ports are loaded by nonlinear reflective loads (two series varactors), a continuous tuning of the excitation phase of a couple of planar antennas can be obtained. An additional meandered rat-race coupler (Fig. 1(a)) makes available a couple of array ports: the sum (Σ) and the difference (Δ) ones. In this way the Monopulse RADAR principle (based on the combination of the S- and D-enhanced radiation patterns information) is exploited while scanning both the patterns. As radiating elements, two planar flag-shaped dipole antennas are adopted (Fig. 1(b)): the double-sided topology allows to obtain a smooth transition from the balanced antenna port to the unbalanced microstrip circuitry, without any additional balun.

This architecture has demonstrated its effectiveness in indoor environments where both the tag-reader distances are not too big (up to 5 m) and clutter or fast fading effects must be faced. In [3], accuracies of few centimetres are feasible up to 3 m-distance. For higher distances, the RSSI-based strategies become not sufficiently accurate.

3. Moving Tags Localization

In order to add the capability of the presented reader to track the movements of tagged people in a bi-dimensional area, additional data processing has been included. Of course, a preliminary calibration is still needed, but it can be very simple thanks to the high accuracy of the angular position measurement previously described. Under the hypothesis of static channel, only three measurements of the maximum Σ RSSI received from the tag are performed: the room is sectored into three radial reading zones (zone #1: -45°÷-22.5°, zone #2: -22.5°÷22.5°, zone #3: 22.5°÷45°) where the tag is placed at a reference distance (i.e., 1 meter).

After the calibration and the real-time measurement of the received RSSI signals, the distance d of the tag from the reader is simply given as:

$$d = 10^{\frac{(P_0 - P_R)}{10 \cdot n}} \qquad (1)$$

where P_0 and P_R are the maximum value of the RSSI received at the reader Σ port during calibration at a distance of one meter and in real-time, respectively, whereas n is the path-loss exponent (depending on the environment under test, typically ranging from 2.7 to 4.3, 2 for free space, down to 1.6 for indoor environments) [5]. For the present demonstration, the number of scanning steps of the reader is programmed to be 40, in order to achieve a fast roughly corresponding to an overall time required for a single-measurement of 200 ms, including the initial overhead for tags ID acquisition and 60 ms dedicated to the dialogue with each tag.

As an experiment, the reader is placed in a real office scenario reported in Fig. 2, where the three calibration zones are visible, too. Two positions of the RFID reader were adopted: in both cases, a path-loss exponent of n=2, has been assumed; the corresponding measured results, reported in Tab. I for the first position of the reader, consist of: i) the real (x_0;y_0) and measured (x_m;y_m) positions, in terms of (x;y) coordinates, ii) the real and measured distances of the tag from the reader obtained by means of (1) doing the average of 10 successive measures; iii) the Percentage Error, taking into account both the x and the y coordinates. Finally, Fig. 3 shows the corresponding map of the room and the exact positions of the measured data.

Figure 2. A picture of the office scenario where measurements are carried out (first position of the reader).

TABLE I
MEASUREMENT IN AN OFFICE SCENARIO (FIRST READER POSITION, N=2)

Point	Actual Position (x_0;y_0)	Measured Position (x_m;y_m)	Distance Reader-Tag	Percentage Error
Point #1	(5.15;1.50)	(5.85;1.25)	1.75	13.86%
Point #2	(2.45;1.20)	(3.10;0.55)	3.79	33.70%
Point #3	(3.35;0.60)	(3.56;0.50)	2.77	6.83%
Point #4	(4.55;0.90)	(4.66;0.90)	1.75	2.37%
Point #5	(5.75;2.00)	(5.96;1.99)	2.02	3.45%

All the coordinates and distances are expressed in meters.

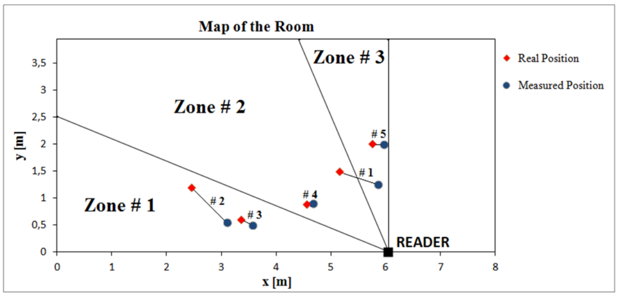

Figure 3. Real and measured positions of the tags for the set of measures of Tab. I. The three calibration zones are also represented.

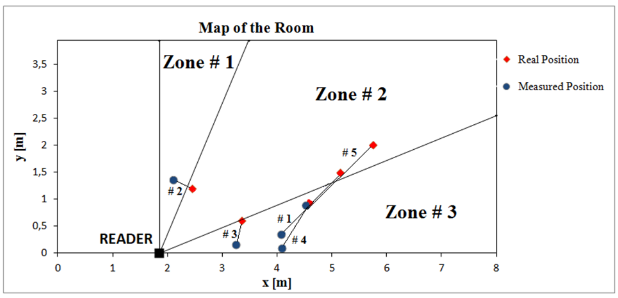

Figure 4. Real and measured positions of the tags for the second set of measurements (second position of the reader, n=2).

From Figs. 3, 4 and Tab. I inspection, it is easy to notice that the highest errors occur for both higher reader-tag distances and in proximity to the calibration zone boundaries (points #1 and #2 in Fig. 3, points #1, #4, #5 in Fig. 4).
In order to cope with this, a suitable a-posteriori data processing has been recently studied and developed: this takes into consideration the fact that the tag is across two zones and recalculate the position thanks to a weighted average considering the different path-loss models and values of received signal strength at 1 meter of the two involved areas. An almost 10% improvement of the corresponding measured error is achieved in this case.
As a further experiment, a real tracking of a tagged person in the same office has been carried out: Fig. 5 shows the top view of the room represented in Fig. 2, with the superposition of the estimated positions retrieved by the reader when the person is moving for 30 seconds among the room furniture. Excellent agreement with actual track is achieved in real-time, in case of reader-tag Line of Sight (LoS).

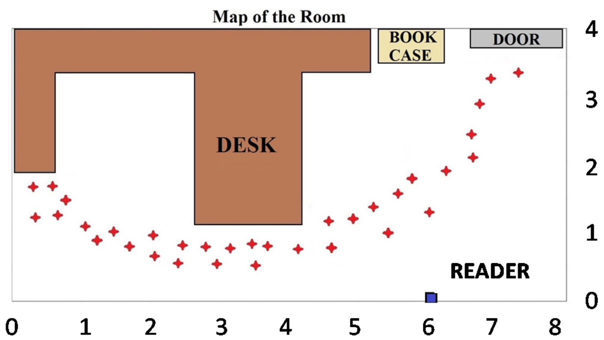

Figure 5. The bi-dimensional map corresponding to the room of Fig. 2, with markers representing the positions where the tag has been tracked in a walk test of about thirty seconds (first reader position).

4. Acknowledgements

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5. References

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