RFID-Based Smart Shelving Storage Systems

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***Abstract* — A RFID-Based Smart Shelving Storage System in UHF band is presented for localization of tagged items with specific reference to a pharmacy drawer for drug storage. Employing RSSI (Received Signal Strength Indicator) information during drawer opening and closing movements, a classification of the tagged item is achieved. During drawer movements, the relative position of tag and reader antenna changes, so allowing for uncorrelated RSSI measurements to exploit with a linear classifier. Measurements in a real scenario are carried out with commercial tags and reader antennas. Location performance is presented in terms of the probability of making a correct decision.**

***Index Terms* — RSSI, Smart Shelf, UHF RFID, localization, linear classification, Smart Drawer.**

I. Introduction

RFID technology has been recently employed in retail and pharmaceutical industries to get automatic real-time inventory, tracking of misplaced items and unattended billing at cashiers. It can be used in many applications such as Item Level Tagging (ILT) in smart shelves [1], proximity point readers and conveyor belts [2] or in smart drawers [3]. Instead of solutions with HF-RFID systems that exploit the near-field inductive coupling, UHF-RFID systems have been employed. Thanks to the EPC-Global Class1 Gen2 protocol, UHF-RFID systems allow for easy-fabrication, low-cost, scalability and simultaneous multiple-tag detection. In addition to classical UHF-RFID systems employing reader and tag antennas operating in the far-field region, Near-Field (NF) UHF-RFID systems can be designed [4]-[5]. In this paper, a localization technique for UHF-RFID smart drawer is presented in order to build an RFID-based smart shelving storage system forward applications such as pharmacy drawers or hospital drug cabinets [6]-[7]. Starting from measurements in a drawer with empty drug boxes, a location algorithm has been developed. The main idea is to employ RSSI (Received Signal Strength Indicator) measurements during the drawer opening and closing operations, to locate tagged items through a linear classification algorithm using only one reader antenna, in order to reduce the total cost of the system. This is one of the principal advantages with respect to existing solutions with multi-antenna readers [8]-[9]. Measurement is described in Section II. The proposed method exploiting a linear classifier is presented Section III and its performance in terms of percentage of correct decision probability are shown in Section IV. Finally, conclusions are drawn in Section V.

II. Measurement set-up

With reference to a measurement campaign in a real scenario, an 80x40 cm^2 wood drawer has been filled with 42 empty drug boxes of different size (Fig. 1a). Each box has been tagged with an UPM Raflatac Rafsec G2 tag in Fig. 1b [10]. The employed reader (Fig. 1c) is the CAEN RFID R4300P ION model able to detect up to 100 tag/s [11] (input power has been set to 500 mW). The reader antenna in Fig. 1d (WANTENNAX007 CAEN RFID [11]) is linearly polarized, with a gain of 8 dBi and HPBW of 60°.

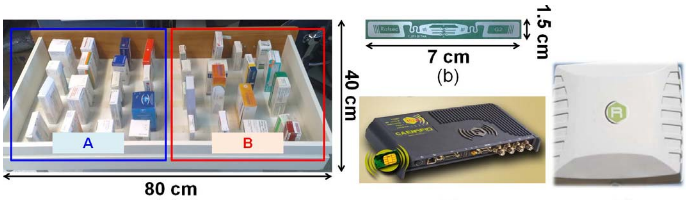


Fig. 1. (a) An 80x40 cm^2 drawer with 42 tagged empty drug-boxes, (b) passive UHF-RFID tag UPM Raflatac RafsecG2, (c) CAEN R4300P ION RFID UHF Reader and (d) RFID reader antenna WANTENNAX007 employed for measurement procedures.

Tagged boxes inside the drawer have been subdivided into two regions (named as region A and region B in Fig. 1a), thus the algorithm goal is to determine the tag belonging region. The reader antenna has been placed along the long drawer side, to get more uncorrelated RSSI measurements during drawer opening/closing (Fig. 2). For simplicity, at the beginning, a polarization matching condition between reader and tag antennas has been considered. RSSI measurements have been collected for different opening/closing movement interval (T).

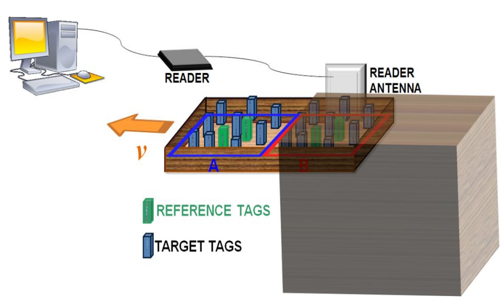


Fig. 2. Scheme of the proposed system exploiting RSSI measurements during drawer opening/closing movement.

III. Linear Classifier

The proposed classification method exploits a conventional algorithm with linear discriminating analysis (LDA), which uses six reference tags, allowing for no calibration procedure. Two different arrangements for the reference tags have been considered: tags aligned along the longer side, in the middle of the drawer (Fig. 3); and tags at the center of each drawer sub-region (Fig. 4).

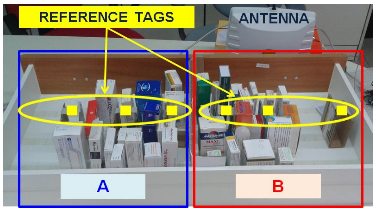


Fig. 3. Drawer scenario with 42 tagged empty drug boxes with reference tags aligned along the longer side, in the middle of the drawer.

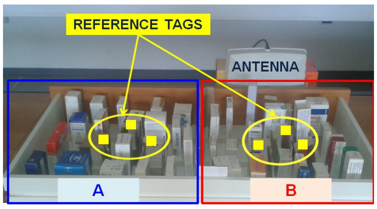


Fig. 4. Drawer scenario with 42 tagged empty drug boxes with reference tags at the center of each drawer sub-region.

For each tagged box, a different number of RSSI samples have been collected during the drawer movement (tags shift with respect to the reader antenna), thus, an average operation of them have to be performed, in order to get the same number of decision variables. Different values of average subintervals (ΔT) have been considered. As an example a 3D scatterplot representation of average RSSI values is represented in Fig. 5.

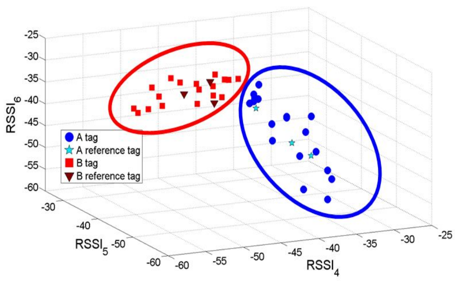


Fig. 5. Scatterplot of RSSI values averaged in a subinterval of ΔT=T/3 for the reference tags aligned along the longer side in the middle of the drawer.

For a given tagged box, each point corresponds to RSSI measured values averaged in a subinterval ΔT=T/3. The point clouds related to tags in region A (blue circle) and region B (red square) are clearly separated allowing to distinguish among tags belonging to the relative region. Furthermore markers related to reference tags are well distributed inside the respective area, demonstrating that they are properly placed to characterize the area itself.

IV. Algorithm Performance

Algorithm performance are shown in terms of relative frequency of occurrence of a correct decision (f_C). For a scenario as that in Fig. 3, with reference tags aligned along the longer size in the middle of the drawer, the relative frequency of occurrence matrix is shown in Fig. 6. Each column represents the number of tags actually belonging to i-region and classified as belonging to the j-region (normalized with respect to the number of tags belonging to the i-region). So, the diagonal terms represent the frequency of correct classifications, while the others are associated to misclassified tags. Two different scan intervals have been considered: T=13 s and a more realistic case of T=5 s. If an average subinterval ΔT=T/3 is chosen, for a uniform tag distribution in the two regions, the relative frequency of occurrence of a correct decision is around f_C=0.96 for the scan interval case T=13 s (Fig. 6a), and slightly different, f_C=0.93, for the case of T=5 s (Fig. 6b).

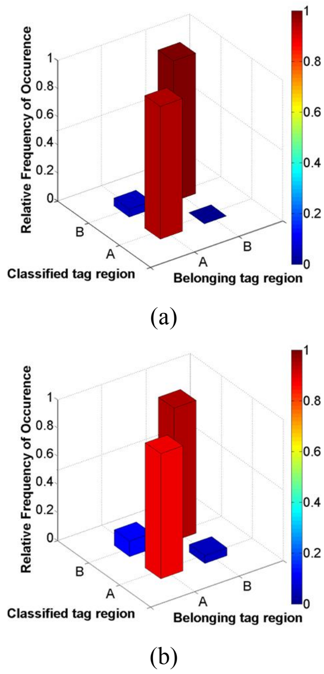
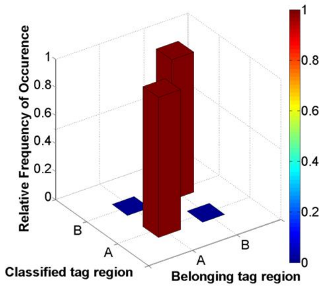
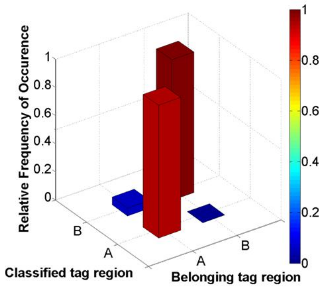


Fig. 6. Relative frequency of occurrence related to the drawer scenario in Fig. 3 with reference tags aligned along the longer side, in the middle of the drawer for two different scan intervals: (a) T=13 s and (b) T=5 s. An average subinterval ΔT=T/3 has been considered.

For the configuration with reference tags at the center of each drawer sub-region (Fig. 4), the relative frequency of occurrence matrix is represented in Fig. 7. For a scan interval of T=13 s (Fig. 7a) the relative frequency of occurrence of a correct decision is around f_C=1 while for T=5s (Fig. 7b) the relative frequency of occurrence of a correct decision is around f_C=0.96. Also in these cases an average subinterval ΔT=T/3 has been chosen.



(a)



(b)

Fig. 7. Relative frequency of occurrence related to the drawer scenario in Fig. 3 with reference tags at the center of each drawer sub-region for two different scan intervals: (a) T=13 s and (b) T=5 s. An average subinterval ΔT=T/3 has been considered.

To test the reliability of the above performance, different random distributions of tagged items inside the drawer have been considered. The relative frequency of occurrence of a correct decision has been calculated for a number of eight test cases for both scan interval values, T=13 s and T=5 s (Fig. 8) and for the reference tag distribution at the center of each drawer sub-region.

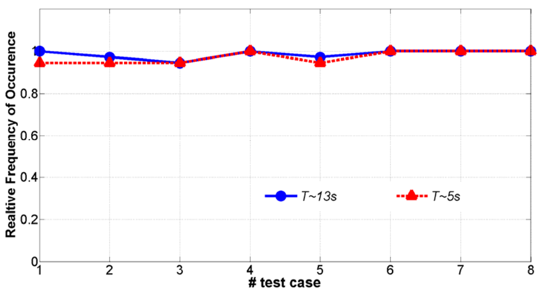


Fig. 8. Relative frequency of occurrence of a correct decision for both scan interval and for the reference tag distribution at the center of each drawer sub-region: T=13 s (circle markers) and T=5 s (triangle markers)

The average relative frequency of occurrence is around 0.98 for both scan intervals, demonstrating reliable performance for random distributions of tagged items.

V. Conclusions

A new smart shelving storage system, with only one reader antenna, for localization of UHF-RFID tagged items in a smart drawer has been presented. Exploiting the drawer opening/closing movements, RSSI samples have been acquired to get more uncorrelated RSSI measurements. Thus, the tag belonging region can be determined, through a linear classifier procedure with average RSSI samples. Robust performance in terms of average relative frequency of occurrence of a correct decision has been shown.

System performance for a random orientation between tags and reader antenna (polarization mismatching) are actually under investigation and results will be shown at the conference.

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