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An Added Value Alternative to RAIN RFID Items Characterization in Retail

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ABSTRACT This paper deals with the difficulties of detecting UHF passive RFID tags in a RAIN RFID system implemented in a retail environment. The aim of this paper is to evolve from the notion of characterizing a tag to the approach of evaluating a tagged item in a system, in order to better understand the behavior of each item coming to life on the internet of things. To achieve this purpose, real store shelves are mounted and filled with 444 tagged products belonging to 24 different product families. Three automatic inventory systems are installed separately in order to perform two types of evaluation: first, the detectability of each product family and second the clustering of tagged items with similar performances in the same group regardless of their product family. Using inventory systems, this type of evaluation, eliminates the need to invest in characterization equipment and introduces a new way of reliably evaluating tagged items directly in the store. It enables the real-time detecting and targeting low-level tagging and arrangement problems without any prior knowledge of the tagged products present in the reading area and their initial quantities.

INDEX TERMS Automatic inventory, clustering, Internet of Things, K-means, machine learning, passive, performance analysis, performances metrics, radiofrequency coverage, RAIN RFID, retail, RFID tags, retail, UHF RFID.

I. INTRODUCTION

RAIN RFID, also known as UHF RFID, is a passive technology that enables the automatic identification of items. Thus, it bridges the gap between the physical and digital worlds by allowing an object to become alive on the internet of things through low-cost, battery-less tags. Each tag is attached to an item, and the term ''tagged items'' becomes the new notion as it makes more sense to address the product itself with all its variables from the material to the form factor and the used tag. Each tagged item is then designed by a unique identifier known as the Electronic Product Code (EPC). Each item of a product family has a unique EPC. A tag is composed of a chip and an antenna. An RFID system is composed of a tag, a reader and the environment they're present in.

RAIN RFID has become the revolutionary technology for the supply chain. In manufacturing, it reduces the cost while improving the visibility. In warehouse management, it improves the accuracy, tracks and records losses and enables locating the products. In the store, the RFID retail processes are based on four fundamental principles: Improving the inventory accuracy, out of stock management, products locating and loss detection. The retail sector remains the main driver of RFID deployment with 4600 million items tagged to date, expected to keep the lead in 2021 with 15000 million tagged items [1].

In [2], the out-of-stock management is identified as a major problem affecting the revenues by a loss of 4%. A model is simulated in order to automate the replenishment decision. In [3], a centralized inventory management system using various configurations (combining fixed and manual mobile readers) was assessed; the concluded disadvantages are related to the technological availability, notably, RF interferences and metallic objects nearby.

The mentioned papers assume that a retail store is RFID enabled which implies that every item is tagged and the proper reading equipment is installed. However, the deployment suffers from several constraints such as tag to tag interferences, reader to tag interferences, the presence of reflectors, the presence of other devices operating on the same frequencies and multipath propagations rendering tags unreadable [4] (or hidden). Aside from the RF constraints, other environmental factors can compromise the performances of the tags themselves such as temperature, humidity, and bending [5]. Most importantly, when tags are placed in proximity to each other's, three well identified and explained factors [6] will affect the performances. These factors are,

detuning, which is due to mutual coupling, shadowing and re-emission cancellation. For the remainder of the paper, the set of these contributing factors will be referred to as the stacking effect.

In order to understand the behavior of the tag and evaluate the performances, several commercial solutions exist. Researchers are also motivated to propose low-cost solutions such as the platform proposed in [7] that succeeded to achieve results equal to commercial solutions.

However, these measurement platforms—while allowing to test on several materials and in creative configurations—remain limited as it is proved impossible to emulate a realistic environment that takes into account the increasing number of tagged items and the RF environmental factors. In [8], a more application-oriented study proposes a new performance metric based on parameters such as the read rate, read distance and read speed. However, we could not consider the results representative of a retail environment due to the small number of tags present in the measurement environment. In [9], in the aim of validating the performances of a robot reader, the inventory accuracy is measured in a real sales space. It is noticed that the inventory accuracy of the products varies while using the same reader, even in a sparse arrangement.

This study is a proposed extension of a previous study covering the performances of UHF tags in different environments. The premise of this paper is threefold: (1) to resume previous results and identify short comings; (2) to analyze and characterize the tagged items in a store without the need to invest in characterization equipment; and finally (3) to characterize tagged items in a retail store without prior knowledge of the tagged items and available quantities. This study aims to provide a better understanding of the overall behavior of UHF passive tag in retail to better deploy an efficient RAIN RFID system and enable retailers to instantly control the performances of a tagged item within it. This step will facilitate the supply chain management and fortify its connections to "Smart Cities" where it is necessary that data is accurately and comprehensively captured in real-time.

II. PREVIOUS WORK

This article is an extension of the prior work done to investigate several variables effect on a UHF RFID tag's performances during the tagging and deployment process. This is studied and published in a previous conference paper [10].

In the base work, the goal was to trace the tag's change in performances along the deployment process. To reach that purpose, an RFID tags deployment process was divided into four phases:

(1) The choice of the tag itself.

(2) The tagging of the product, meaning, attaching tags to every product.

(3) Placing tagged products on the shelves in an ideal environment, also referred to as the arrangement of the tagged product.

(4) Placing the full shelves in a retail store.

In (1), the Friis equation for free space would apply and other factors would not affect the parameters of the tag. The tag is tested in an anechoic box (1.20 x 0.80 x 0.80 cm) In (2), the product material will modify the equation by affecting the gain of tag antenna and the antenna to tag matching (detuning factor). The tagged product is also tested in an anechoic box in the same conditions as in (1).

In (3) the arrangement effect, is represented by metallic objects placed in the near field (degrading the detuning factor and antenna gain), orientation mismatch due to placement of the tagged items arbitrarily on the shelves, and the stacking effect when tags are placed in close proximity. The tests are carried out in an anechoic chamber (7x7x3 m). Finally, in addition to the previous parameters, in (4), the multipath enters in play and the link budget is measured directly in a retail showroom. The shelves occupy a 4x0.8x2.2 m volume and are placed in a spacey showroom.

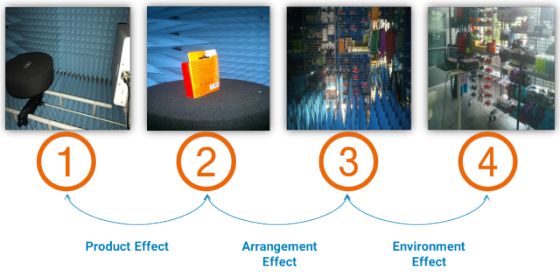

FIGURE 1. Four measurements configurations from left to right: tag alone in an anechoic box, tagged product in an anechoic box, tagged products in shelves in an anechoic chamber and complete shelves in a real store.

As illustrated in Figure 1, by performing the measurements in these four environments, the extraction of the product effect, arrangement effect, and environment effect was possible. In this context, the change rate (Γ)—a new metric—was defined. It quantifies the decrease or increase of the needed emitted power in order to activate a tag between two environments.

The results show that the tag loses all its intrinsic characteristics. On the other hand, its performances' constraints are rather defined by its arrangement in the shelves than any other variant in the environment. This implicates that the tag chip sensitivity and initial read range measured in step (1) are not reliable characteristics of a deployed tag. Finally, the link budget reveals the positive effect of the multipath in a real store environment especially when the arrangements are highly constraining [10].

Throughout the measurement and analysis in each phase of the study, two conclusions stand out. First, it is important to replace the concept of a standalone tag by the concept of a tagged item which implicates a product and a placement/configuration. Secondly, in a realistic setup, tagged items tend to belong to different performances levels, regardless of the used tags. Hence, the possibility of creating several groups based on performances.

In hindsight, the measurements are carried out using a commercial characterization tool which implicates that a retailer, wishing to analyze the performances of his tagged items, will have to make considerable investments. In addition, the tags' performances also depend on the entire RFID system. For example, depending on the type and placement of the readers, the evaluation of the performances will vary. Hence, a limitation concerning the repeatability and practicality of the carried study prevails.

In order to level with these difficulties, this study proposes a new methodology based on using an already installed inventory system to evaluate the tagged items. Two approaches are considered.

The new methodology will enable the possibility to test all present readable tags and draw conclusions on each one individually as opposed to the previously tested method that only allowed conclusion on product families with enough read items in it. The shelves are then re-arranged and more challenging tagged products are used to test its efficiency.

III. METHODOLOGY

Based on previous work and observations, two questions drove this study and helped define the approaches.

The first question relates to the possibility of diviging the tagged items performances in a real store. In other words, how to divide unique tagged items into different groups based on their performances and perform accurate analysis of the situation. The second question, considers the feasibility and practicality of the proposed system to carry the performance analysis.

Following these questions, two corresponding approaches arose. The first approach was to measure the detectability of each tagged items family, given the available tag's EPCs and quantities for each family. The second is a statistical approach, with the ability to evaluate the performances without any prior knowledge of the tagged items and quantities.

A. TAGGED ITEMS DETECTABILITY

First, the performances of the tagged items are analyzed using different RFID systems. The idea is to perform a complete inventory with a fixed reading system and then get all the read tagged items EPCs. This approach requires knowledge of all the tagged items present in the store. For this purpose, real store shelves are constructed and filled with tagged items (sports goods) as shown in Figure 2.

The used items, range from simple and easy to tag (such as a t-shirt), to more complicated (such as small tubes) and complex products (small items with metallic components).

Table 1a shows the products families and the total items present in each. Table 1b shows the tag associated with each product. The tag's chip, reference and chip sensitivity are presented. The sensitivity value presented in the table is only for reference (provided by the manufacturer) and does not represent the overall sensitivity of the tag; which is prone to change due to different factors such as antenna-chip impedance mismatch, orientation mismatch as well as other factors [10].

FIGURE 2. Target products arranged on shelves and placed in a real store environment.

TABLE 1. (a) Products families and the total number of items available in each. (b) Used tags and associated products.

Product	Description	Total products present by group
A	Backpack - Green/Green	7
B	Backpack - Purple/Pink	7
C	Backpack - Blue/Orange	10
D	Backpack - Navy/Blue	10
E	Backpack - Pink/Brown	16
F	Backpack - Gray/Blue	16
G	Backpack - Gray/Orange	16
H	T-Shirt on Hanger	20
I	Vibrations dampener	20
J	Slim Ropes	5
K	Inner Tube	14
L	Shoes (upper part of shelves)	9
M	Powerbar Tubes	95
N	Tomato protein powder	8
O	Break cable	12
P	Bicycle Chain	15
Q	Shoes (Lower part of shelves)	18
R	Shorts	8
S	Rolled T-shirts	9
T	Ping Pong balls	10
U	Bottles	57
V	Grey Square T-shirt	21
W	Lamps in boxes	14
X	Towels	27

(a)

Tag reference - Chip	Tagged Product	Chip read sensitivity
Zephyr 1 – G2iL	H, L, Q, V	-18 dBm
Web – G2iL	A, B, C, D, E, F, G, M, N, W	
AD383 – U7	K, X, P, U	-21 dBm
Zephyr 2 – U7	R, S, I, O	
AD320 – U7	J, T	

(b)

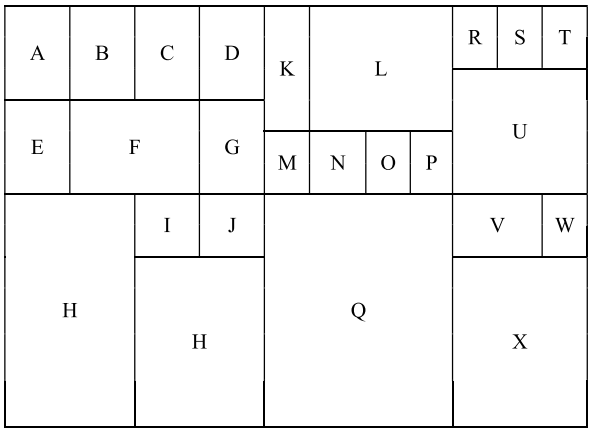

FIGURE 3. Representation of products families in a 2D grid.

To measure the detectability of each family of tagged items, the percentage of reading EPCs over the total present EPCs is calculated. Each item in a product family will have a different EPC. To visualize the performances disparities, a 2D grid is defined in the plane facing the antennae as shown in Figure 3. Each case contains the detectability score as defined by equation (1). For example, if two products from the A family (total of 7 items) are read, the case will score 28%. Thus, knowing the quanities of each of the products families is essential in order to calculate the detectability scores. The detectability of each product's family will be calculated using three different reading situations including a combination of two systems and three installations. Three grids will be drawn for each reader set to the optimal reading parameters.

$$Detectability\ score = \frac{Detected\ EPCs}{Total\ present\ EPCs} \tag{1}$$

B. PERFORMANCES CLUSTERS

Secondly, the performances of the tagged items are studied beyond the detectability alone. The study carries on analyzing the performances depending on two indicators: the RSSI (Received signal strength indicator) and the RC (read count) in one inventory round. The tagged items will be then clustered into distinct performances groups based on one, two or both of the indicators. In order to do so, a machine learning technique, known as k-mean clustering, is employed. This technique aims to partition n observations into k clusters.

As seen in paragraph A, the first approach requires that the products quantities are known for each family. However, this information is not always available especially in the early stages of adoption of the technology. This approach does not require a prior knowledge of the present tagged items in a store because it processes the reading data of each EPC separately. Moreover, this method permits to access each EPC individually and independently from its product's family allowing a retailer to conclude on the performances trends based on its arrangement—proven to be the most critical parameter—and to pick a more suitable tag choice and placement. Add to that, the possibility to measure the impact of the adjustment of the reading system's physical set-up and protocol parameters in order to enhance the coverage.

IV. TAGS PERFORMANCES IN RETAIL

A. USED READERS

Two reading systems are used to perform the tests. The first system is a house-assembled RFID reading system using two circularly polarized (one left-hand Ref: S8658PCL and another right-hand Ref: S8658PCR) Laird antennae and two ThingMagic M6E RFID modules with a measured sensitivity of −80 dBm. Each module is connected to one antenna with three meters coaxial cables with 1.5 dB loss. The gain of each antenna is of 8.5 dBic and provides a 3 dB beamwidth coverage area of 70°.

The second system is a high-end commercial RFID reading system based on a Speedway Revolution enclosed reader. This system achieves a maximum read sensitivity of −84 dBm with an active array that could achieve 52 beams by varying the amplitude phase and polarization on each physical antenna. Enabling all 52 beams provides a circular 3 dB beamwidth coverage area of approximately 120°. In other words, the system will transmit full power − 3 dB towards a tag that is offset by 60° from directly under it.

The Equivalent Radiated Power (ERP) for all system is equal to 33 dBm as per regulations in France [11].

B. PROTOCOL PARAMETERS

Both RAIN RFID readers are GS1 compliant and implement the Gen2 protocol [12]. The choice of parameters configuration affect directly the reader's query and the tag's response, thus impacting the overall performances of the UHF RFID system.

The used systems' interfaces offer the possibility to configure the following parameters: Backscatter Link Frequency (BLF), Type A Reference Interval (TARI), Tag encoding, target, session and Q parameters used to regulate the number of slots for tags responses.

The effect of Gen2 parameters has been studied and although no major effect was recorded for the encoding in [13], the Pulse width (directly affected by the TARI) seemed to have an improving effect on the sensitivity when it is lower. In spite of these finding, a Miller4 (M = 4) is privileged since the field contains a significate population of tags rather than just one in [13]. A Miller4 is a compromise on data rates in order to limit the interferences. A TARI of 12.5 μs is chosen as a compromise between better data rates and better sensitivity.

In [14], the choice of the Q parameter was subject to examination given its effect on the throughput and the read rate. The best throughput is theoretically achieved when the number of slots is equal to the number of tags present in the field. The throughput could be increased further when the BLF is low.

In this case, we choose a number of slots superior to the number of tags present in the shelves, which is convenient,

since it's placed in a real store environment and parasitic tags are present. Thus for a population of 444, a Q of 9 is chosen (L = 512 slots).

The BLF is chosen as a function of the previous choices (related to Q, Tari and encoding) equivalent to 250 KHz.

To better understand the choice of the session, the flag or the status must be taken into consideration. A flag or status could have the value 'A' or 'B'. If the reader is set to target 'A' tags, in one inventory round, 'A' tags will be read and set to 'B'. 'B' tags will not be read. The duration of persistence (how much time an inventoried tag remains in its state) is defined by the session.

A session 1 with an 'A' target is chosen in order to record various readings of the same unique tags between different inventory rounds. This session is privileged because the tag reverts from one status/flag to another several time whether it's in or out of the RF field. In session 1, a read tag is silent for a time between 0.5 and 5 seconds (refer to table 6.20 in [12]), thus permitting various reading over a reading round (several inventory queries) while reducing the traffic at the same time.

C. PHYSICAL PARAMETERS

In order to better understand the behavior of tags in a complete RFID system implemented in a real store, three physical configurations are suggested.

First (case A), the house assembled solution is placed at 1.7 meters in front of the shelves and a height of 1.5 meters as shown in Figure 4.

FIGURE 4. Two Laird antennae placed in front of the shelves (case A).

Secondly (case B), to better understand and evaluate the effect of item-reader link, both antennae are placed overhead at the same distance of 1.7 meters to the center of the shelves (top of the shelves to antennae distance is 1.2 meters) at a height of 2.5 meters as shown in Figure 5. The antennae are tilted 30° to the back in order to better face the entirety of the shelves.

Finally (case C), to evaluate the effect of the reading system quality on the tagged items performances, a high-end commercial reader is mounted overhead at the same distance from the shelves and at a height of 2.5 meters.

FIGURE 5. Two Laird antennae mounted overhead, above the shelves (case B).

In all three cases, two antennae (array antennae with embedded readers in case C) are mounted at a distance of 1.2 m from each other's.

D. RESULTS AND DISCUSSION

A reading round for each reading system of 5 minutes was defined in order to permit multiple readings of a tag in session 1 while making sure all tags had a chance to respond. The worst read rate measured for all systems records 387 tags per second. Each reader returned the read EPCs. By comparing the database of all the present tagged items in the field, to the read EPCs returned by the reader, an EPC item receives 1 if it was read, 0 if not. Then the sum of the read EPCs for each product family is calculated in order to calculate its detectability score as defined in equation (1).

After processing the data of the inventory reading tests, we find out that the commercial reader (case C) achieved the best detection percentage of 72% followed by the house-assembled system mounted overhead (case B) with 70% and finally the same system installed in front of the shelves (case A) at 62%. This shallow look at the results validates the dependence between the several components of a RAIN RFID system (tag, reader, and link). The reading phase is repeated 3 times in order to ensure, that for the same configuration, same physical installation, and same reading round duration, the same reading percentage is achieved.

In order to better understand the behavior of the tags, the detectability score of each product family is calculated and visualized on the 2D grid pre-defined above in Figure 3. Results for the cases A, B and C are reported respectively in Figure 6, 7 and 8.

First, by taking an overall look at the three grids, it is obvious that the coverage efficiency of the zones moves from one reader to the other, thus proving that performances are highly dependent of the reading system parameters. While the in front system covers better the products in the face, the overhead system enhances the coverage on the top of the shelves. It is observed that the overhead system is more efficient than the in the front system (where the reader faces the product) due to the different and unpredictable orientation of the tag

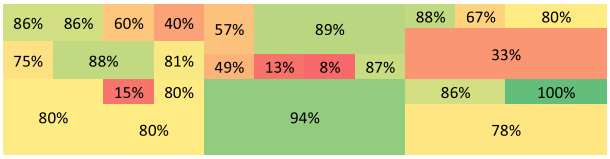

FIGURE 6. Detection map of the house-assembled system when antennae are placed in front (case A).

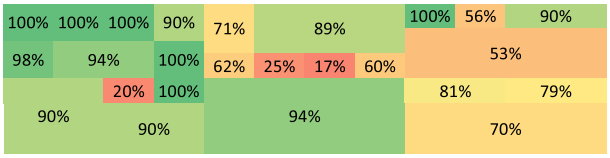

FIGURE 7. Detection map of the house-assembled system when antennae are mounted overhead (case B).

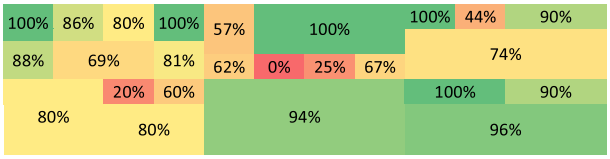

FIGURE 8. Detection map of the high-end commercial reader when two antennae are mounted overhead (case C).

affected by the product's form and the arrangement. By looking at the two mounted overhead readers, it is deduced that the commercial reader (case C) achieves better overall coverage due to the beam steering, while the house-assembled (case B) achieves higher scores but at focused zones of the shelves.

Secondly, it is clear that no matter what reading system is used, there are always several performances categories. In this case, the tagged items could be distributed over four categories: Green (90-100%) where tags are easy to read, Yellow (75-90%) where the items are properly tagged but not in the optimal placement relative to the reader, Orange(30-70%) where there's a room for improvement on the tagging but mostly the effect of arrangement dominates and Yellow (0-20%) where wrong tagging choices are made or items are placed in very constraining arrangements.

Finally, a general conclusion could be drawn by analyzing the three grids together that is some categories will depend on the installation and coverage of the readers (zones changing colors between green, orange and yellow from one reader to another) and other categories will signal a serious alert about the tagging choice and arrangement of the products such as the red zones which remain weak regardless of the reader and the configuration. The three identified weak cases are the vibration dampener (close stacking), tomato flavored proteins (bad tagging on Aluminum packaging) and finally the 'break cables' (metallic parts close to the tag).

This method only provides an overall view of the tagged products family's performances while unable to distinguish between the performances of two read EPCs. The clustering technique is then proposed to introduce an additional analysis dimension based on radiofrequency performance indicators.

Most interestingly, this method validates three tendencies concluded in [10]:

1- The tendency of tags to lose their initial characteristics when they are placed in a real environment (products with same tags do not behave similarly).
2- The arrangement tends to have the major effect on performances.
3- The tagged products tend to form several groups of performances.

In addition, this method highlight the reader-tag link in the definitive reading configuration and suggests that tags in the same product family may have different performances based on their positions on the shelves.

V. CLUSTERING OF TAGGED ITEMS

While the first approach allows visualizing the coverage and drawing some conclusions on the performances of the system, it is still limited. In order to get accurate results, a proper knowledge of the items present on the shelves is necessary. However, the knowledge of present tagged items in the system is not always available or perfected. In order to better understand the behavior of each tagged item without any prior knowledge of the items present on the shelves, we look into the reading data such as the read count (RC) and the received signal strength indicator (RSSI) for each EPC. Then to analyze the data, we use a machine learning technique, k-means clustering, to group EPCs with similar behavior regardless of the product family they belong to. This will allow us to place data items into groups so that similar items are in the same group and dissimilar items are in different groups. Clustering is multidimensional and could be performed with one, two dimensions or more. As a matter of fact, clustering is not a foreign technique to the RFID as it is used for localizing tags by grouping unknown tags with reference tags. In [15], the k-NN (nearest neighbor algorithm) is used in order to improve the localization of the tags. These techniques discussed the use of both phase and RSSI as indicators to group the tags present in similar positions. In this case, the phase is disregarded since location information is not interesting for the purpose but rather constitutes noise since EPCs present in the same area do not necessarily have the same behavior. Aside from that, the RSSI (similarity) variation and unreliability caused by the multipath is put to question as the response from one inventory round (query) to another will vary. Based on the above, we consider a different indicator, which is the read count that records the number of times a tagged item was read during a specific amount of time.

A. K-MEANS CLUSTERING

More specifically, the used technique for clustering is k-means and it requires the pre-definition of the number of desired clusters (k) and the data to be grouped (tuples).

The proposed algorithm simply initializes the clusters by selecting k centroids (means), assigning other data points to the closest cluster center, and updating means and clusters until two consecutive rounds return the same clusters [16].

This algorithm is either 1 dimensional or multidimensional. In order to enhance the performances of a multidimensional system, the data is normalized so that the values of the read count (varies between 0 and 1000) do not get more importance than the RSSI values (usually between −50 and −81 dBm). This scaling will allow both data to have an equal effect on the clustering. Table 2 contains the pseudo-code for a two dimensional k-means algorithm. In case the RSSI value is used to group the items, only the recorded average of the RSSI value over the complete reading round will be registered, in order to attenuate the effect of multipath.

TABLE 2. Pseudo-Code for a two-dimensional k-means algorithm.

2-dimensional clustering: RC and RSSI
Get reading data
Group data by EPC while averaging RSSI and summing the read counts from all the inventory rounds
Normalize data
Initialize clusters
Clusters the data into k groups where k is predefined.
Select k points at random as cluster centers.
Update clusters and centroid
While (change is detected between two consecutive runs)
Assign objects to their closest cluster center according to the Euclidean distance function.
Calculate the centroid or mean of all objects in each cluster.
End While

For example, if a tagged item returns an RSSI of −70 dBm in one inventory round and then an RSSI of −73 dBm in another round, the recorded result would be −71.5 dBm. As the RSSI is averaged over multiple rounds, the value will be closer to the most frequented path by the wave from the tagged product to the reader.

However, if the read count is recorded, the sum of the total read counts is taken into account since the read count is binary and a tag is either read or not read in an inventory round. This means over 100 rounds, if the tag is read at all times, it will record 1 in each round and at the end the sum (100) is recorded.

By adopting this statistical approach, the tester will not need to know what tags they should expect to read. The evaluation will be relative and different performances categories will be identified.

B. RESULTS AND DISCUSSION

For this study, the idea was to run multiple inventory rounds (100) for the duration of 5 minutes, save the read data, and then group the EPCs based on RC values. The RC values are considered alone because the RSSI values would introduce errors caused by the multipath thus degrading the clustering accuracy. The house-assembled system mounted on overhead is used for the facility of implementation of the algorithm and at the same time more realistic automatic inventory setup than readers in front of the shelve. We run the test for 3 clusters (k = 3) based on the read count (RC) values, where cluster 0 contains the worst performing items and cluster 2 the best. The best case would have the highest read count, and the worst case would have the lowest read count over the same period of time. The same inventory time is kept for convenience. The number of clusters is chosen by the user. For deep analysis, the number of clusters should be higher in order to look closely at the behavior of tagged items. In this case, 3 clusters are chosen to highlight three performances categories. Clustering is relative, which means, a good performing category is only good relative to other present categories in the same RFID system (same reader, physical installation, shelves...).

TABLE 3. Items scattering on three different performances clusters to provide more in-depth analysis of the detectability score.

Product families	Items scattering among categories (K-means clustering)			Detectability score from previous approach (Section IV)
	Cluster 0	Cluster 1	Cluster 2	
A	67%	33%	0%	100%
B	50%	0%	50%	100%
C	57%	0%	43%	100%
D	0%	0%	100%	90%
E	0%	0%	100%	98%
F	43%	14%	43%	94%
G	0%	0%	100%	100%
H	11%	0%	89%	90%
I	80%	20%	0%	20%
J	40%	0%	60%	100%
K	9%	0%	91%	71%
L	0%	44%	56%	89%
M	23%	0%	77%	62%
N	100%	0%	0%	25%
O	100%	0%	0%	17%
P	0%	33%	67%	60%
Q	0%	8%	92%	94%
R	0%	33%	67%	100%
S	33%	0%	67%	56%
T	0%	25%	75%	90%
U	17%	33%	50%	53%
V	13%	7%	80%	81%
W	0%	44%	56%	79%
X	18%	9%	73%	70%

For example an average of 100 read counts might be considered high for a system where the read count range is between 0 and 100 but would be considered low in another more efficient system where the read count range is much higher (0 to 1000). This detail might be used as a simple indicator to rate the performances of various systems or configurations by comparing the average of the weak clusters. To understand the advantages of this method compared to the previous approach, the scattering of the products across the three clusters is compared to the detectability score of each product family. The results detailed in Table 3 show that beyond the detectability score, there are other indicators critical to the performances of the system. A fully read product family does not mean that the coverage of the system is

optimal, neither is it a confirmation that the tagged items are easy to read.

As a reminder, the house-assembled system (case B) is mounted at the ceiling in front of the top of the shelves and has two antennae with a 3dB beamwidth of 70°. Both antennae are separated of a distance of 120 cm from each other's and symmetrically, 60 cm from the center of the shelves with a tilt of 30°. To better understand the results of the clustering we consider two performances tendencies: high detectability score (>90%) and low detectability score (<25%).

1) LOW PERFORMING TAGGED ITEMS

If we first consider the weak tagged items (low detectability score) such as 'I', 'N' and 'O', all EPCs will always be classified in the cluster 0 (worst performances). The Product 'I' shows that 20% of the detected items are classed in cluster 1, which might be due to its proximity from the floor which increases its chances of being detected in stacked configurations due to multipath [10]. This shows that the weak detectability of a product family is related to the weak performances (low read counts) of each item in this family thus signaling a tagging or/and an arrangement problem.

2) HIGH PERFORMING TAGGED ITEMS

Next, we consider good tagged items with high detectability scores (> 90%). The twelve product families are highlighted in green and grey in the results table. The analysis of this tendency is divided into three stages due to its complexity. In stage 1, we'll look at the families where almost all products are placed in the best performances category (cluster 2) and none in the worst category (cluster 0); this gives us the products 'D', 'G', 'Q'. Their performances are explained by looking at the 2D grid illustrated in figure 3, which clearly shows that these three products families are placed directly in front of the antennae in a relatively average arrangement difficulty.

In stage 2, we look at products where most of the items are still in cluster 2, but a noticeable portion of items is assigned to either cluster 1 or 0. Families 'R' and 'T' are distributed between clusters 2 and 1, which is mainly due to their position in small zones on the upper part of shelves (at the same level as the line-of-sight of 30° tilted antenna). Families 'H' and 'J' have items distributed in clusters 2 and 0. The difficulties of reading for these two items are issued from their proximity to the lower part of the grid (far from the antenna) in addition to the stacked configuration, especially obvious in the case of 'J' where 40% of the items are classified in cluster 0.

In stage 3, items families 'A', 'B', 'C' have been identified for having a majority (> 50%) of items outside of cluster 2. This is due to their position on the weak gain area above the 30° tilted antenna. Items belonging to 'A' are mostly placed in cluster 0 and show lower performances due to their presence on the extremity of the shelves.

3) INCOHERENCES AND IMPROVEMENT PROPOSAL

Finally, product families 'E' and 'F' exhibit also good performances with respectively 98% and 94% detectability scores. However, the clustering of their items does not correspond as they both have the same arrangement of their products at close positions in the grid. This is not reflected in the results since 'E' items are all present in cluster 2 while 'F' has 43% of its items in cluster 0. 'E' belongs to an intersection of two performances categories: good position vertically opposed to the reader's antenna line-of-sight and a challenging position horizontally as they are present at the extremity of the shelves. 'F', also belongs to two performances categories between 'E' and 'G' with products scattered on a more significant zones. This constitutes an incoherence that is due to the Read counts close to the averages (means) of two clusters. While, intuitively, the RSSI was disregarded as a second indicator for clustering, the need for a two-dimensional system arises in order to enhance the clustering precision. Future proposal shall focus on a correction technique of the RSSI values in order to use it as a clustering parameter with the read count.

4) LESSON LEARNED AND EXPLOITATION

The first method depends on a well implemented retail process that gives full visibility of present products on the shelves. It does not take into account the loss of tagged items and increases the risks of error in an increasingly developing ecosystem based on the automatic collection of data. Any data loss will implicate a compromised knowledge of the shelves resulting in erroneous detectability scores.

The second method, k-means clustering is relative to a reading system, this way we can enhance the tagging and also place the antennae and move them in retrospect of the weak spots. The big advantage, however, remains the ability to evaluate the performances of tagged items without any prior knowledge of the EPC of the tags present in the reading area.

First, the focus is shifted to tagged items that belong to product families that are either very easy ('D', 'G', 'Q') or very hard ('I', 'N', 'O') to detect. The easy products to read recorded high detectability score and a high clustering in the cluster 2. The hard products recorded weak detectability score and high clustering in cluster 0. A close to perfect correlation is perceived between the clustering of the unique EPCs and the detectability score of the product family.

Secondly, while an obvious comparison with the results obtained in [10] is not possible due to different approaches, the same tendencies are validated. It is possible to regroup tagged products according to their performances, the arrangement has the major effect on the performances of the tag, and more specifically, the tagged items in a stacked configuration always undergo the heaviest performances decrease.

Third, by looking at the performances of each EPC in a 3D environment, the clustering method enables the coverage enhancement and ensures its reliability by identifying weak performing tagged items. It is then possible to assess the

efficiency of a reader's coverage by comparing the average read count of the lowest performances category between several physical installations or several protocol and power configurations.

Finally, beyond the coverage, the second technique allows us to explore the performances of each EPC on the shelves, thus facilitating the possibility of reconsidering the tagging solution for various products families. Finally, the in-depth analysis of the groups facilitates the recognition of performances pattern between EPCs from different product families based on their arrangements, placement relative to the reader and tagging approach.

VI. ADDED VALUE OF THE NEW EVALUATION METHOD

An RFID system deployed for automatic inventory is used in order to classify the tagged products into different performances groups. This is only logical since in [10], we were able to conclude that the tags tend to regroup into different performances levels independently of their initial intrinsic characteristics. Furthermore, the tagged products were evaluated in the actual inventory scenario, which means that this evaluation method takes into account the placement of the tag relative to the reader and could be performed with any system installation. This is important since in retail—where space saving is very important—we often do not have control over the placement of the readers. Most importantly, the evaluation was done without any prior knowledge of the quantities of tags on the shelves. The initial quantities are especially important to be known when evaluating the performance of the system; they provide a reference for the tester to calculate the detectability score (equation 1). For example, if 2 products are read and the available quantity is 2, the performances are far more superior than if the available quantity is 10. This detectability score will indicate which product families are well detected and which are not. However, the quantity information is not always available, neither it is accurate when available, especially in early adoption stages [17]. Hence, the importance of an evaluation process independent of the known initial quantities.

The benefits are mainly to simplify the testing procedure, limit investments in traditional characterization tools, and finally, provide a more pertinent, real-time analysis of the performances of a tag without any prior knowledge of the initial quantities of tagged products.

VII. CONCLUSION

The main objective was to propose a new method to evaluate the performances of tags in realistic retail environments.

Two methods were proposed using implemented automatic inventory systems, thus, eliminating the need to invest in special characterization equipment. The first method relies on the detection ability of a system in order to evaluate the performances of products families. The second relies on the RSSI and read count values of every unique tagged item. The coherence between the detectability score of each product's family and the characterization proposed in [10] validates the arrangement effect. The second method (clustering) adds one more layer of analysis without any prior knowledge of the items on the shelves to reveal weaknesses behind 100% detectability scores and alerts on possible reading problems.

Observations and analysis show that weakly performing items will keep weak performances throughout different systems; which often signifies a serious tagging or arrangement problem. It is also highlighted that clustering offers the possibility to analyze each item of a product by accessing its EPC and concluding on its performances relative to each and every variable in the system. This level of information allows and facilitates the collection of data in order to find different patterns of performances across different product categories in a complete shelve. This proposed evaluation method is advantageous—especially in earlier adoption phases—since it provides the tester with high level of information about the performances without any knowledge of the tagged items present in the reading area.

Such findings would inspire defining a new metric to score equipment installation efficiency and eventually adjusting a reader's physical (ex. Positions) and protocol parameters to enhance the score and consequently the global performances of the system.

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