Passive ultra high frequency radio frequency identification systems for single-item identification in food supply chains

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Abstract

In the food industry, composition, size, and shape of items are much less regular than in other commodities sectors. In addition, a wide variety of packaging, composed by different materials, is employed. As material, size and shape of items to which the tag should be attached strongly influence the minimum power requested for tag functioning, performance improvements can be achieved only selecting suitable radio frequency (RF) identifiers for the specific combination of food product and packaging. When dealing with logistics units, the dynamic reading of a vast number of tags could originate simultaneous broadcasting of signals (tag-to-tag collisions) that could affect reading rates and the overall reliability of the identification procedure. This paper reports the results of an analysis of the reading performance of ultra high frequency radio frequency identification systems for multiple static and dynamic electronic identification of food packed products in controlled conditions. Products were considered when arranged on a logistics pallet. The effects on reading rate of different factors, among which the product type, the gate configuration, the field polarisation, the power output of the RF reader, the interrogation protocol configuration as well as the transit speed, the number of tags and their interactions were statistically analysed and compared.

Introduction

As food products are mostly perishable or at least with an expiring date, monitoring and controlling the supply chain by efficient systems can lead to huge enhancement of safety and value (Grunow and Piramuthu, 2013).

Automation in data-capture in manufacturing, logistics, warehousing and retail, has enhanced the capability of monitoring the path of a food product from raw material to consumer, at affordable costs (Tortia *et al.*, 2010; Dabbene *et al.*, 2014). By means of radio frequency identification (RFID) auto-identification systems, the food item auto-identify itself (auto-ID) during its handling along the whole supply chain, wirelessly and without line of sight, even in movement and in presence of many other similar items in the reading field (Delen *et al.*, 2007).

Nevertheless, in the food sector some issues remain to be addressed for the application of RFID. These include reading reliability which in some cases is still to be improved, due to the difficulties encountered in the identification of entities in critical and very different contexts as farms, factories, cold and moist storage and transport. Moreover, RFID identification is complicated due to the food composition and the harsh environment where food is manipulated and stored, which both affect electromagnetic fields. As a consequence, some noticeable technical difficulties to obtain exhaustive and reliable identification of food items in critical production environments are encountered (Clarke *et al.*, 2006; Mühlmann and Witschnig, 2007). One negative effect on tag performances, both in static and dynamic conditions, is the variation of the electric field in the proximity of a food object due to its dielectric properties, which influence reflections, transmission and absorption rates (Barge *et al.*, 2014).

The potentialities of RFID can lead to a drastic improvement of the food supply chain, enhancing the reliability and the granularity of information collection during processing, inventory and shipment till the point of sale (self-replenishment, customer information, anti-counterfeiting, *etc.*). RFID benefits include reducing out-of-stocks through item-level visibility of storeroom and shelf inventories, reducing the mis-shipments by promoting more accurate shipping, and preventing product counterfeiting, diversions and theft through mass, reliable, item-level identification (Penttilä *et al.*, 2006). RFID offers high benefits also in monitoring the cool supply chain of fresh produce, linking passive tags and active RFID devices, which acquire continuously *e.g.*, temperature or moisture (Aung and Chang, 2014).

In warehousing and delivering, single items can be grouped and contained in secondary and tertiary packaging units and shipped in heterogeneous batches to retailers (Zhou, 2009). The identification can be performed statically (identified object is still) or dynamically (objects are moved along a path in the reader coverage area).

The capability of identifying objects even contained in packaging at different levels (boxes, bundle, item) allows customising

data management at each production stage without assembling or disassembling lots. Electronic systems allow decoupling physically the two fluxes: information collection and items movements. Collected data can be accessed and managed at different detail level on distributed information networks.

Reading efficiency has to be very high: to guarantee the robustness of the traceability system the reliability of detecting multiple tags - even dynamically - has to be carefully assessed.

To achieve the complete detection of all items in dense environment, criticalities of the systems have to be afforded and solved. In some cases, when a wide tag population lays in the reading field, a phenomenon called tag-to-tag collision can occur if the interrogator is unable to send and receive signals from different tags contemporaneously (Jankowski-Mihulowicz *et al.*, 2008).

The accuracy in completing the inventory of a tag population is crucial for RFID systems adoption. Beside the technical and physical characteristics of the system (*e.g.*, bitrate, frequency modulation, *etc.*), the proper settings in interrogation protocol have to be carefully chosen in function of: number of tag, type of product, speed of the tag set in the reading area, *etc.* (Prodanoff, 2010). The system is intended to improve RFID static and dynamic multiple identification for packed food products which allow goods localisation, automatic count, and inventory management through the supply chain (Alyahya *et al.*, 2016).

This paper investigates how the parameters of the EPCglobal Inc™ Class-1 Generation-2 (EPC Class-1 Gen-2) protocol can influence performances in the detection of a tag population attached to packed food items. For the better understanding of the paper, the following paragraphs report a discussion on the Aloha-based protocol which is used in the common standard EPC Class-1 Gen-2, the most adopted in ultra high frequency (UHF) RFID systems. *Materials and methods* section describes the details of the experimentation, while *Results* and *Discussion* sections report the results and the discussion, respectively.

Backgrounds

In supply chain management, where medium-range and high-speed identification is required, the EPC Class-1 Gen-2 operating in the 860 MHz - 960 MHz frequency range is nowadays the most diffused standard (EPCglobal Inc™, 2005).

According to the EPC Class-1 Gen-2 protocol, when the interrogator powers up, it energizes all tags by the operating carrier wave which is in the range 902-928 MHz (in the U.S. Federal Communication Commission), while in the 865-868 MHz frequency band in Europe, assigned by the European standard ETSI EN 302 208 (European Telecommunications Standards Institute, 2008).

Herein, the physical and logical requirements for a passive-backscatter, interrogator-talks-first system, are defined. To solve problems encountered when interrogating simultaneously a tag population, an anti-collision algorithm, based on dynamic framed slotted Aloha method, has been adopted. The resolution of tag collisions is made by broadcasting a series of commands by the reader and responses transmitted by the tag.

The anti-collision algorithm applies rules for the uplink of the tags by slotted frames. The *Query* command initiates the first *Inventory round*. Following the Q-algorithm of the Aloha protocol (Chin and Klair, 2010), the frame size is adjusted during interrogation by the parameter Q. Each of the energized tags randomly chooses and deposit in the slot counter a value $\overline{Q}$ in the range $0 \leq \overline{Q} \leq 2^Q - 1$, for an integer value of Q in the range 0-15. Tags that have $\overline{Q}$ equal to zero in the slot counter respond immediately to the

reader command, while the others remain in the arbitrate waiting for other query commands (*Query Repeat, Query Adjust*) which decrease or reset the slot counter till it reaches zero. If more than one tag has acquired the value zero in the slot counter $\overline{Q}$, a collision occurs and the reader is unable to reply.

If in the slot is present only one tag, the reader replies to the tag. In the reply state, the tag selects and transmits a 16 bit random number called RN16. The RN16 is then acquired by the reader which gives back the *ACK* (acknowledge) command, allowing the tag to finally backscatter its 96-bits identification code. If the ID code is not correctly received or some kind of error occurs, a *NAK* (negative acknowledgement) command sent by the reader resets the tag status to the arbitrate state.

When they are powered up, tags are set with an *Inventoried* flag which can be in A or B state. When the reader starts a *Query*, only tags with the corresponding *Inventoried* flag are allowed to answer during the round. The tag inverts its *Inventoried* flag after the transmission of its identification code.

A *Query Round* is defined as the interval between two *Queries*. A series of *Query Rounds* between power-down periods are reported as *Query Cycle* (Buettner and Wetherall, 2008).

To obtain the correct reading of a population of tags, a strategy has to be put in place properly setting some of the interrogation key-parameters.

In order to reduce empty slots and collisions, commercial readers can be set to an initial *Q* value which is adjusted in arbitrating during inventory rounds to best accommodate the number of tag remaining to be read. Nevertheless, until it starts counting the tags, the reader cannot estimate the tag number and choses an initial Q that can be very far from the optimal one, reducing channel efficiency.

Query Cycle may consist of a series of *Query Rounds* with the target set to one flag (A or B). As tags are read, and their Inventoried flags are switched to B, they become inactive during subsequent *Query*. When a *Query* elicits no tag responses, as all tags have changed their inventoried flags, the *Query Cycle* ends and the carrier wave powers down. When the inventoried flag of each tag is reset to the initial state, the transponder will be active during the next *Query Cycle*.

The EPC Class-1 Gen-2 standard allows for up to four sessions (0, 1, 2, and 3), which is the inventory of one reader with a defined set of tags. The session is opened by the *Query* command that initiates the round. Herein a session S is chosen among S0, S1, S2, and S3. The sessions are used both to determine how often a tag will respond to a query from the reader or allows for multiple readers to conduct independent inventories (this latter is not our case as we used only one reader).

For the different sessions, the persistence of the inventory tag varies: when the tag is energized, for each query cycle the persistence time of the inventoried flag value is indefinite for S0, S2 and S3, while is in the range 0.5-5 s for S1 session. When a *Query Cycle* is finished and the reader powers down, the inventoried flags are set to the initial state for S0, while in S1 persist for a time in a range 0.5-5 s and for S2 and S3 persist for at least 2 s.

Materials and methods

To evaluate the performances of UHF identification systems for food packed products, experimentation on items housed in secondary packaging was carried out both in static and in dynamic conditions. A metallic RFID gate equipped with up to four UHF

antennas for the simultaneous reading of a large number of electronically identified packed food items arranged on a pallet was constructed. Two kinds of food materials were used for trials: dry food and beverage contained in their original packaging and stacked on homogeneous pallets. Different technological solutions were evaluated in terms of reading accuracy of tags applied on secondary packaging, considering static and dynamic reading conditions and different antenna layouts.

Food products

Food items were stacked on a pallet in their final packaging simulating the delivering phase. The considered bakery sweet snacks (28 g each, 30×105×25 mm) are packaged in a first sealed bag in polypropylene and inserted in a small paperboard box (140×60×210 mm) wrapped by a further polypropylene film sealed bag containing ten snacks each. These packs are arranged in a corrugated carton box (0.30×0.40×0.25 m), which contains a total of 120 sweet snacks. The chosen beverage was ice tea (200 mL volume), contained in cylinder-like plastic cups (85 mm high) with aluminium top cap. The void volume between tea surface and cap was 7 mL. Six of these cups were inserted on a 130×205 mm carton tray. Trays were superimposed and placed in a carton box (0.28×0.56×0.22 m). Each corrugated carton box of ice tea contained 72 single cups.

Corrugated carton boxes were arranged on a pallet following the scheme in Figure 1, each identified attaching a RFID tag in vertical position in the centre of the external minor side. For sweet snacks, the pallet was composed by 45 corrugated carton boxes arranged in five horizontal rows (overall dimensions 1.50×1.15×0.80 m). In the case of ice tea, the pallet was composed by 21 carton boxes stacked in three horizontal rows (overall dimensions 0.84×1.10×0.78 m).

Radio frequency identification reader and antennas

Tag interrogation was performed using a compliant standalone reader connected to one or two couples of antennas: Caen RFID, model Wantenna X007, 8 dBi gain, linear polarisation or Caen RFID, model Wantenna X005, 7 dBi gain, circular polarisation EPC Class-1 Gen-2, ETSI EN 302208 (865 MHz to 868 MHz).

Antennas were fastened on a 2.60 m high and 2.75 m width iron gate (Figure 2) at variable heights and configurations in function of pallet type (Sanghera *et al.,* 2007; Dobkin, 2008). As the aim of the present study was to evaluate the effect of the reader settings on reading rate, tags were optimally oriented parallel to the electric field generated by the linear antenna. Both in static and dynamic trials, two antennas couples were mounted in frontal and parallel position placed at 0.65 and 1.37 m height from the concrete floor for sweet snacks. In the case of the ice tea, only one
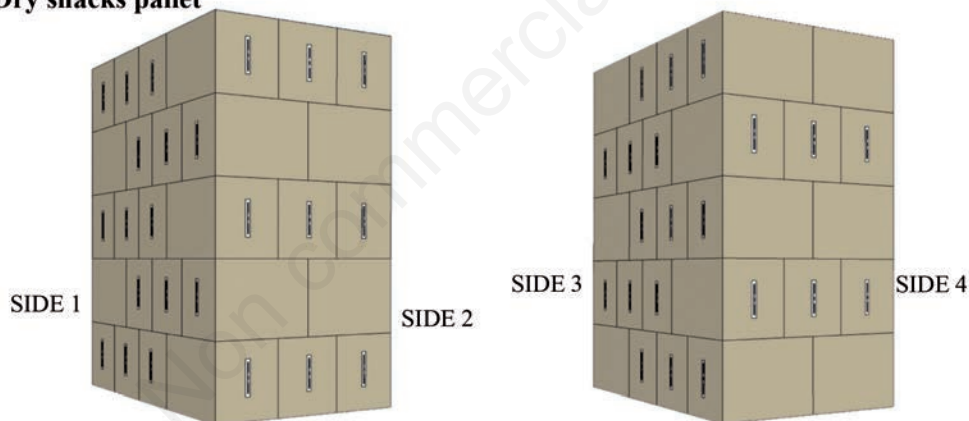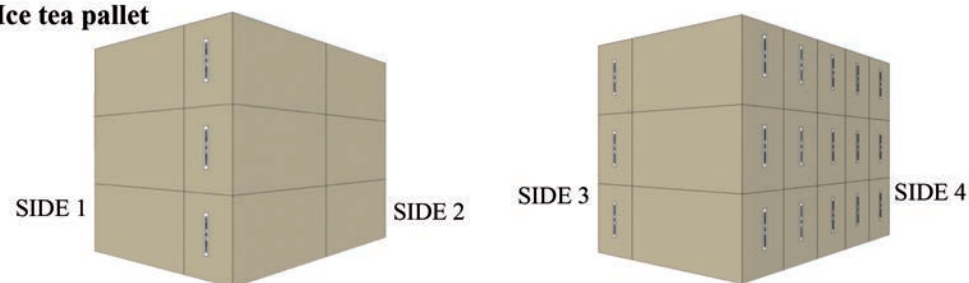

Figure 1. Dry snack and ice tea pallets setup. On the pallets are superimposed 45 or 21 carton boxes respectively. Each carton box is electronically identified by means of an ultra high frequency radio frequency identification transponder (UH331 LabID) applied on the carton box minor side, in external position.

couple of antennas was placed at 0.75 m because of the limited height of the pallet. In order to minimise electromagnetic wave reflection, any metal objects was kept away from the working environment. Transmitter power output (TPO) was set at different levels in the range 23-32 dBm. Reading time was set to 3 s.

The UHF reader was controlled by a specific software developed in C# by our research group, which allows acquiring separate inventories by each UHF antenna.

A single inventory cycle is performed in turn by each antenna in the following order: Ant0, Ant1, Ant2, and Ant3. The software allows choosing the parameter Q, which determines the number of time slotted frames in the range of Q 1-12, for each inventory and session (0, 1, or 2). A fixed frequency band was used, choosing the same channel value (channel 0). The complete logs of the whole inventory split in sub-inventories performed by each antenna were acquired.

Tag

An EPC Class-1 Gen-2 compliant UHF passive aluminium dipole (95×7.2 mm), LabID UH331, was chosen on the basis of previous results, as reported by Barge *et al.* (2013). It is equipped with an Impinj Monza 5 integrated circuit which has been designed to work in environment with high density of tags.

Static and dynamic identification trials

The system performance in inventorying food cases by passive multiple identification was considered both statically and dynamically. In static trials the pallet was centrally positioned under the RFID gate with the major side orientated towards the antennas. Inventories were then performed in order to evaluate different sessions (S0, S1, S2) and Q values effect on reading efficiency. Session S3 was not considered as technically identical to S2. On the basis of the Aloha protocol, the optimal Q value is equal to the base 2 logarithm of the total number of tag present in the reading area. Therefore, in the case of ice tea, the theoretical Q value should be 4 or 5 (16 or 32 available slots), while for sweet snacks 5 or 6 (32 or 64 available slots). The design of the static identification experiment was a complete matrix of the combination of EPC Class-1 Gen-2 six different initial Q (in the range 1-6) and three session S (0, 1, or 2). Ten repetitions for each combination were performed. TPO was set at 23 dBm during this experiment. Inventory was recorded in a time lapse of 3 s and the complete tag inventory log was recorded. During the cycle, the four antennas power up in sequence (Ant0, Ant1, Ant2, and Ant3).

The log was elaborated counting all the reading cycles and the number of tag acquired by each antenna in each single cycle.

The error rate was calculated as percentage of missed/total tags in the reading area considering the whole 3 s time frame. For each combination, at least 20 repetitions were conducted. One-way analysis of variance (ANOVA) was performed for each product on the dependent variable error rate for the factors session and Q; *post hoc* Duncan test to discriminate groups at P<0.05 was chosen.

In other trials, readability in function of power level was essayed in the range 23-27 dBm. In dynamic identification trials, the pallet was manually moved through the gate using a forklift at different speeds ranging from 0.8 to 1.20 ms^{-1} on a 5 m straight path. The pallet was always forked from the narrower side: in this way, the larger side of the pallet was parallel to the antennas plane.

Experiments were performed in controlled conditions to evaluate the effect of Q and S on dynamic reading efficiency (DRE%, number of transponders correctly acquired/number of transponders in the electromagnetic field). The efficiency was analysed consid-

ering separately the two products and configuring the gate by linear polarisation antennas. In the experimental design the variable trolley speed was added registering the time spent in displacing the trolley manually. The experimental matrix considered the two products, six levels of Q, three session types, and three trolley speeds. Total number of combinations was 108. The influence of the factor session and Q on the variables number of cycles performed by the group of antennas, idle cycles and dynamic reading efficiency was analysed by a linear general model analysis of variance (UNIANOVA) procedure for regression analysis. *Post hoc* Duncan test to discriminate groups at P<0.01 was chosen.

Results

The following results are related to the influence of EPC anti-collision protocol parameters on the correct tag acquisition in static and dynamic identification of food items.

Static identification

Static reading efficiency resulted to be strongly affected by the considered product. In the case of bakery sweet snacks, inventory was more reliable. Using the linear polarisation antenna, the complete set of tags was correctly inventoried at 23 dBm TPO in all the trial rounds and with all the Q values and sessions (0, 1, and 2).

On the contrary, the error rate in ice tea boxes inventory was very high both using linear or circular polarisation antenna. In particular, at 23 dbm, none of the tag was detected by the circular polarisation antenna when attached to ice tea boxes. In previous research conducted in controlled conditions on a single ice tea box identified by the same tag, good results in terms of power requested for activation were obtained also in comparison with other combination of tag type and bottled edible liquids (Tortia *et al.*, 2012). The low performance of the system for identification of several items stacked on a pallet could be ascribed to the energy dissipation due to the large liquid mass and to the eventual coverage of some tags which could be shielded by other boxes.

In the sweet snacks/circular polarisation antenna and ice tea/linear polarisation antenna combinations, inventories were not complete. The error rate resulted in the range 2.5-4.0% for the bakery snack and 23.8-24.3% for the ice tea. This was expected as for

Figure 2. Gate framework: dimension and antenna position for pallets ultra high frequency electronic identification. In case of ice tea pallet only 0 and 3 antennas were used.

snacks the water content is very low and metal parts or materials that are known to degrade electromagnetic fields are not contained in the packaging. Conversely, the cups full of water solution and the aluminium film seal on the top of the primary packaging strongly affected readability. From the results obtained using the circular polarisation antenna, inventories resulted to be incomplete for both products. As this could be ascribed to the fact that the circular polarisation antenna has a lower gain, the TPO was enhanced up to 27 dBm, but ice tea inventory errors rates were still very high (data not reported). Nevertheless, using the linear polarised antenna, the TPO enhancement up to 27 dBm yielded a complete inventory of the tag set as could be seen in Figure 3, which reports the results on inventory errors at different power levels. Since the detection by circular polarisation antenna of tags attached to the ice tea boxes was very poor, the combination ice tea/circular polarised antenna was excluded in the following trials. When tags are inventoried in subsets on the basis of session 2, the error is significantly lower, as could be seen both in Figure 3 as well as in Table 1, which report, as an example, the influence of both query parameters (S and Q) on the error rate in inventorying snacks by the circular polarisation antenna. Comparable results in session 2 were obtained by the linear polarisation antenna for ice tea (data not reported). The best reading efficiency was obtained when the frame size Q was set equal to 3. The error rate was not linearly influenced by the parameter Q.

To detect causes of errors in accuracy and to examine potential inefficiency due to idle periods of the reader or redundant readings of the same tag during the inventory, the total number of cycles performed by the reader in the whole 3 s time frame were calculated on the basis of the inventory log related to each antenna.

In Figure 4 are reported the means of the inventory cycles performed by the reader for the considered products, antenna type, Q and session values. For both products and both electromagnetic field polarisations, the number of cycles significantly linearly decreases when slot number is large (larger Q values). Duncan test discriminated groups at $P<0.01$ in all the cases. In our experiment the cycles number is referred to the number of cycles that the reader can perform in a 3 s time lapse and not to the number of cycles requested for the identification of all the tag set. Then, if the cycles are shorter in time, their total number will increase.

This is probably due to the fact that, increasing the frame size, the time spent to arbitrating and scheduling the transmission of the

Table 1. Inventory error rates (% missed tags/total tag population) in static identification of carton boxes containing bakery snacks by circular polarisation antenna for different frame sizes (Q) and sessions (S0, S1, and S2).

Q	S0	S1	S2	Mean	Std. dev.
1	3.9	4.4	2.8	3.5[d]	1.73
2	5.2	3.7	2.2	3.4[d]	1.40
3	2.2	4.4	2.7	2.8[e]	0.97
4	5.2	3.0	2.2	3.1[de]	1.37
5	3.1	4.4	2.2	3.5[d]	1.11
6	4.4	2.2	3.0	3.1[e]	1.11
Mean	4.0[a]	3.8[a]	2.5[b]	3.23	-
Std. dev.	1.58	1.03	1.09	-	1.37

Std. dev., standard deviation. [a-e]Different letters indicate means significantly different at Duncan test for $P<0.05$.

Ice tea/linear polarization

Sweet snacks/circular polarization

Sweet snacks/linear polarization

Figure 4. Mean cycles number, for each Q and session value, in static identification the two products and antenna polarisation. Means are referred to all the three-combination antenna type/product.
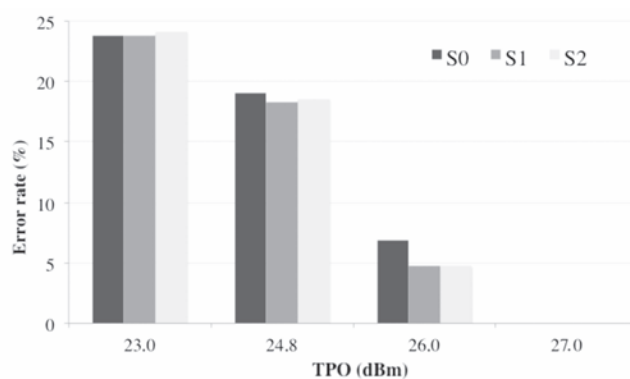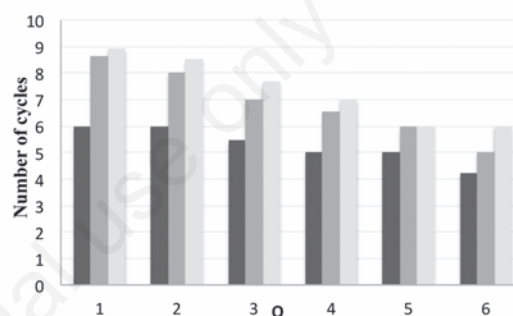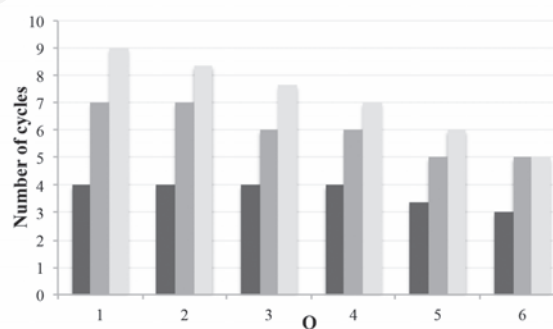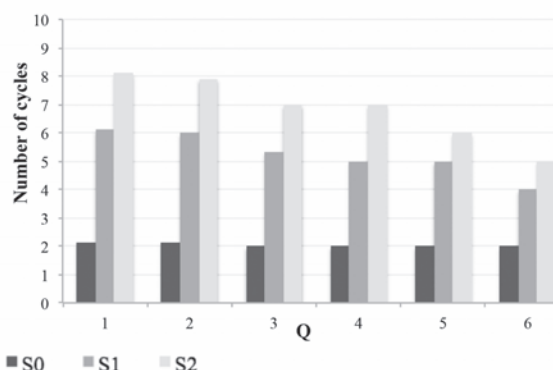

Figure 3. Error rate (% missed tags/total tags set) in static identification of packed ice tea at different transmitter power output (TPO) levels by linear polarisation antennas.

tags in each slot is higher, as can be seen also from the results of Vogt (2002). Buettner and Wetherall (2008) demonstrated that in case of high collision rate and in presence of errors, cycle duration increases.

The session type significantly influenced (P<0.01) the number of cycles performed by the reader for both antenna type and product (Figure 5). If session type did not exclude already acquired tags (as in the case of S0) also the cycles number is lower than using a session type (S1 and S2) which selects only tag subsets on the basis of the tag flag status (A or B). In fact, when the reader starts a new cycle in session 0, it has to acquire the whole tag set, then is very busy to acknowledge each transponder and solve all the collisions that occur when a wide population of tags has to be identified. Besides, it is known that the acknowledge commands are the most time consuming among the different phases of the tag inventory as the reader waits for the transmission of the entire EPC ID (Buettner and Wetherall, 2008). Moreover, *Query* commands that are repeated, *e.g.*, to decrease the slot number and the needs to transmit the missed acknowledgement of the code (*NAK* command), increase cycle length. The efficiency of session 0 operation mode is very low, as the channel results to be busy for most of the acquisition time. In addition, the error rate is not reduced (Table 1).

As the tag population is less dense, like in the case of ice tea, the time spent in arbitrating during each round decreases and the total number of rounds increases (Figures 4 and 5). Besides, the reader has to switch only to two antennas mounted on the gate, reducing cycle duration.

The time spent by the reader to acknowledge tags can be evinced in Figures 6, which reports the tag acquisition rate (detected tags per cycle) for each antenna and in each reading cycle in the three sessions (0, 1 and 2) in the case of bakery snack and circular polarisation antenna. While for session zero the channel is dedicated to acquisition during all the 3 s lapse time, in the case of session 2 most of the tags are acknowledged already in the first cycle and by the first antenna while the following cycles are mostly empty and therefore the channel is idle for a considerable time.

In session 1, the acquisition in the first cycle is very similar to session 2 but, after the period of persistence of the flag (0.5-5 s) the transponder can answer again to the reader and another peak in the curve of tag detection is displayed.
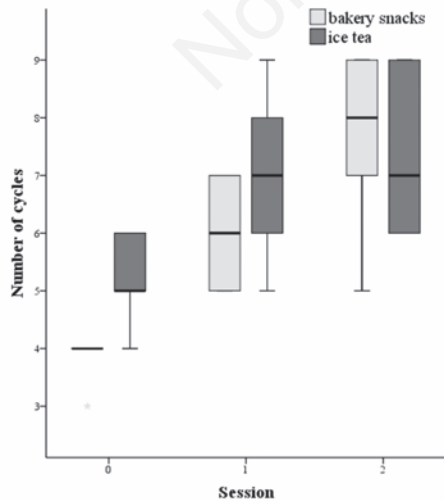
Dynamic identification

Results obtained in dynamic trials proved that motion of the tags in front of the antennas improves readability with respect to static conditions. The difference is particularly significant in the case of ice tea.

The dynamic reading efficiency inventory was very high for bakery snacks, and inventories were always complete in session 1 and 2 (Table 2). For ice tea the accuracy was improved up to 99.35% DRE (mean of the three sessions), with a maximum of 100% DRE when Q was 1, 3, or 4 (Table 3).
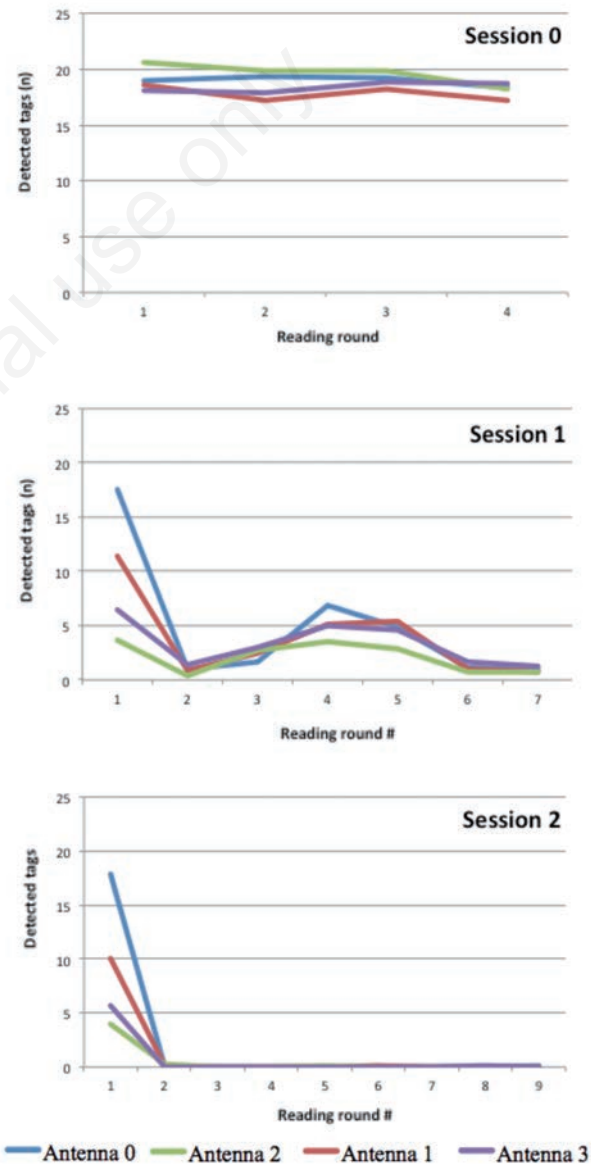

Figure 6. Tags detected by the four antennas in sequence in static conditions. The product was bakery snacks, circular polarisation antennas.

Figure 5. Mean cycles number per session value and product. Means are referred to all the three combination, antenna type/product and Q values.

The obtained general linear model regression explains the influence of both factors Q and session and their interaction on the variable total number of cycles performed by the whole set of antennas (R^2=0.932 for bakery snacks and 0.993 for ice tea). Duncan test separates group with significantly different means at P<0.01. As already proved in static conditions, the total number of cycles performed by the reader when the tags transit through the RFID gate during 5 s acquisition was higher in the case of ice tea with respect to bakery snacks. As in static conditions, cycles number is significantly higher in session 2 for both products (Table 2). Cycles are fewer at wider frame size and for ice tea the mean of the groups were highly significantly different (Table 3).

In the considered range, the variable speed did not significantly affect the inventory accuracy, nor the rate of idle cycles or the total number of cycles. For both products, in session 2 the reader is mostly idle during the 5 s of total acquisition time (Table 2), due to the fact that the reader partitions the groups of already acknowledged tags and has not to acquire more than one time the same transponder. When the tag population is wider, as for bakery snacks boxes, the saving in acquisition time is greater as the collisions in session 0 and 1 are more conspicuous. The factor Q has not significant effects on the idle cycles ratio. Only with Q equal to 6 mean values significantly differ but the effect is opposite for the two products. This could be ascribed to the high number of tags and the low number of cycles in the case of bakery snacks.

Discussion

On the basis of the obtained results, considerations could be assessed on the overall performances of UHF gates in inventorying food goods statically or dynamically. When the tag remains still in a reading field area, the efficiency of the tag/reader antenna coupling in each unit of a tag set does not change during the time interval. This can result in a very low probability that less favoured tags have chance to be detected if the configuration persists (*e.g.*, misalignment, orientation, shields by other materials, shadowing effect of other tags, blind spots in the reading area) as in static conditions. In this case, high level of accuracy cannot be reached only by changing the anti-collision algorithm parameters, but a considerable power increase is needed, especially in case of products which cause strong signal reflection and attenuation.

This has been noted also with a product which cause limited electromagnetic wave dissipation. When the tag moves through the reading area, tag to antenna mutual orientation changes during time and the same tag has the opportunity to turn in more favoured position to be detected. This effect is clearly evidenced by the fact that, in the considered speed range, the displacement of the product can improve tag to antenna coupling, increasing reading efficiency also in the case of high water content products. This confirms the results obtained by Tortia *et al.* (2010) who considered a UHF system for potted plants identification on a spinning trolley.

The problem of orientation is often solved by using circular polarisation antenna, however it has been seen that power has to be strongly enhanced and very poor results are achievable on critical products as beverage even if the tag is optimally oriented.

The configuration of anti-collision parameters of the reader has shown to influence more the efficiency in terms of reducing and optimising acquisition time of the hardware employed, reducing idle time, than on accuracy of the inventory. As the time spent to complete a cycle implies a cost, the increase in system performance in terms of tag identification speed and query success rate may have consequences on total costs in running the system,

Table 2. Total number of cycles and percentage of idle cycles performed in the 5 s-time interval by the set of linear antennas in dynamic conditions for bakery snacks and ice tea for sessions (S0, S1, and S2) on.

S	Bakery snacks			Ice tea		
	DRE %	Cycles (n)	Idle cycles (%)	DRE %	Cycles (n)	Idle cycles (%)
0	99.75	3.39[a]	5.21[a]	98.9	27.00[a]	50.78[a]
1	100	4.22[b]	9.14[a]	99.2	27.16[a]	55.79[b]
2	100	7.17[c]	62.57[b]	99.8	27.88[b]	82.12[c]
Mean	99.9	4.93	25.64	99.35	27.4	64.95
Std. dev.	0.006	1.92	30.53	0.019	5.00	15.43

DRE, dynamic reading efficiency; Std. dev., standard deviation. [a-c]Different letters indicate means in the same column significantly different at Duncan test for P<0.05.

Table 3. Total number of cycles and percentage of idle cycles performed in the 5 s-time interval by the set of linear antennas in dynamic conditions for bakery snacks and ice tea depending on the frame size Q.

Q	Bakery snacks			Ice tea		
	DRE %	Cycles (n)	Idle cycles (%)	DRE %	Cycles (n)	Idle cycles (%)
1	100	5.78[a]	27.93[a]	100	34.22[a]	63.00[a]
2	100	5.33[ab]	30.48[a]	98.9	33.00[b]	62.67[a]
3	100	5.33[ab]	25.20[a]	100	29.56[c]	61.44[a]
4	100	4.89[bc]	25.69[a]	100	26.67[d]	62.56[a]
5	100	4.33[cd]	32.18[a]	98.5	24.20[e]	65.70[ab]
6	99.5	3.89[d]	12.36[b]	99.1	21.63[f]	70.19[b]
Mean	99.9	4.93	25.64	99.35	27.40	64.95
Std. dev.	0.006	1.92	30.53	0.019	5.00	15.43

DRE, dynamic reading efficiency; Std. dev., standard deviation. [a-c]Different letters indicate means in the same column significantly different at Duncan test for P<0.05.

intended as economical cost as well as technical cost, intended as time employed by the system which is not strictly connected by the tag acquisition but dedicated to other activities (*e.g.*, error management or duplicates). Moreover, both the presence of void slot and idle (or void) cycle are avoided reducing the energy consumed and increasing the inventory speed.

Conclusions

The effects on UHF system performance of the gate configuration and the reader anti-collision parameters were assessed and discussed, as well as the difference in RFID identification in static or dynamic conditions.

In the implementation of the RFID system in food warehouses the proper tuning of the interrogation protocol during inventory can improve reading efficiency and reduce technical cost due to the idle time of the equipment. However, as also partially showed in this paper, it has to take carefully in account that, in case of certain products and packaging materials, the reading efficiency should be enhanced tuning other factors as, for example, transmitted power levels, orientation, positioning, tag type. In spite, in other less critical cases (as bakery snacks) the identification can be performed even at item level, allowing to identify multiple objects contained in different type of packaging.

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