Location through Proximity in RFID Systems

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Abstract. In this paper we introduce *Location Estimation through Proximity Information* (LEPI), an algorithm that aims at locating portable RFID readers in areas where active-RFID grids are settled. Location estimation is accomplished through a proximity information, which the reader derives by performing tag interrogation at increasing RF power levels. RFID tags surrounding the reader are incrementally detected and their known positions are eventually averaged, this providing an accurate estimation of the reader location. The performance of the proposed approach is assessed by experimental trials, conducted in indoor environments. They testify both to the actual feasibility of such a solution and to its better accuracy when compared to other reference RFID-based location techniques.

1 Introduction

Radio Frequency IDentification (RFID) is rapidly emerging as a pervasive technology, capable to spread over many different communications, industrial and entertainment application fields. The working scenarios currently envisaged for RFID systems are much broader than the initial one (simple replacement of optical bar-codes) and give rise to the futuristic vision of an *Internet of Things* [1], where RFID tags are deployed on a fairly ubiquitous basis. In such a dynamic environment, new ways to exploit RFID potential are of major interest.

In this paper we will explore the operation of RFID as a technology to locate objects and people either in indoor or even in limited-area outdoor environments. More specifically, we assume to work in a scenarios where, due to the presence of an excessive number of physical obstacles, classical localization solutions, such as Global Positioning System (GPS) or ultrasound systems [10], turns to be unfeasible or too expensive. Based on the target of the location procedures that exploit RFID systems, we distinguish between *tag-oriented* and *reader-oriented* positioning solutions. The former aim at locating RFID tags, while the latter intend to find the position of portable RFID readers. Both approaches are likely to be employed as a basis to implement ”location based” services, although their application scenarios are reasonably much wider.

In fact, tag-oriented solutions require to equip the locating target with a simple RFID tag, that usually can't provide any further networking functions than standard read/write operations. Thus, since there is no immediate way to process location information directly at the locating target, such approaches are well suited for services that

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don't require positioning information to be spread and exploited directly by the located object. Rather, they can be employed to compute target locations and likely process them in a centralized manner, i.e. with the aid of external information systems. Applications that could benefit from such solutions comprise objects/goods localization, e.g. inventory management of goods in logistics systems, or even people positioning, e.g. remote localization of people in special environments, such as hospitals or stores just to make some examples. Key point in the envisaged scenarios is the use of a *single technology* (RFID) for both *identification* and *location* purposes at the same time.

Differently, reader-oriented approaches require the locating target to hold a portable RFID reader, larger and more expensive than a simple tag and usually (but not necessarily) hosted by either a PDA, a laptop PC or a smart-phone. Such devices offer further computational and networking capabilities and, thus, can provide more complex applications; these latter are, typically, built upon raw positioning data and enhanced through either local or network-retrieved information. Thus, reader-oriented solutions fit people/vehicle location services that require the locating target to obtain direct knowledge of its position. Common examples of such services are: localized advertisement, guidance/map provisioning (e.g. in museums, squares, large buildings), location of stock mover cars in indoor warehouses.

In [2] we assessed the performance achievable by some reader-oriented approaches. In this paper we propose and assess, by experimental trials, a reader-oriented location algorithm called *Location Estimation through Proximity Information* (LEPI), that tries to enhance the proximity information collected by a portable reader (i.e. the plain identification data concerning the set of active tags reachable through its interrogations) by means of relevant RF power measures. These can help in selecting the actually closest tags and, finally, are used to infer the reader location.

This paper is organized as follows. In Section 2 we provide an overview of previous works on localization through RFID systems and discuss the main benefits and limitations. In Section 3 we report in detail the rationale of our approach and describe the LEPI operational behavior from a general perspective. Subsequently, Section 4 focuses on the experimental results obtained as the output of field tests that aim at comparing our approach with other RFID localization solutions and at evaluating the impact some system parameters have on the location accuracy. Finally, in Section 5 we draw our conclusions and envisage possible evolutions of the research.

2 Related Work

In the last few years, RFID based localization techniques have been investigated from the point of view of several specific applications. As introduced in the previous section, we suggest a classification into two main design approaches, depending on the actual target of the positioning procedures: RFID *tag-oriented* location solutions, which aim at locating RFID tags, and RFID *reader-oriented* location solutions, which intend to provide a portable reader with an estimate of its own position.

Earlier work on the former class of solutions is well synthesized by LANDMARC [3], which proposes to locate an active RFID tag through RF-power distances with respect to other RFID tags, used as *reference tags* and deployed at fixed, known locations.

More specifically, spatial maps of *Received Signal Strength* (RSS) measures are build dynamically, thanks to the presence of the reference tags. Through the *k-nearest neighbor* algorithm applied in the RSS space, the k closest reference tags are selected and the location of the target tag is finally estimated as a suitable average among the positions of such nearest reference tags. In our previous work [2], we conducted a wide campaign to evaluate the actual performance of LANDMARC under general experimental conditions, while considering both indoor and outdoor scenarios. We concluded that such tag-oriented algorithms require highly expensive infrastructures, including numerous RFID tags and RFID readers/antennas, if satisfactory positioning accuracies are required, especially in indoor environments.

As for *reader-oriented* location solutions, [4] proposes to spread a very large number of passive RFID tags, that can act as reference tags, over the area of interest, thus creating a so-called *Super-distributed RFID tag infrastructure*. A portable reader position can be inferred either through the identification of the closest reference tag surrounding it or, in case of multiple tags identification, even by simple averaging the positions of the identified tags. As a possible application, the authors suggest to track the trajectory of a moving reader over a super-distributed RFID tags grid. Similar approaches have also been studied in the field of assistance to blind people [5, 6] and in robot localization [7]. In [5, 6] RFID readers, embedded in shoes or in walking sticks of visually impaired people, are used to collect proximity information from RFID tags spread across the operating area. The main emphasis in the cited papers is on defining application scenarios, rather than on conducting in-depth analyses on location procedures and on their best operational and project parameters. In robotics, the issue of locating RFID readers has been investigated in [7], where statistical filters are exploited to enhance odometry information by means of RFID tag identification.

In [9] a classification similar to the one introduced in the present paper is shown. In particular, the *Active scheme* aiming at providing the localization of a portable reader and the *Passive scheme* for localization of a tagged item are outlined. The target position is assessed through a nonlinear optimization method that minimize an error objective function.

The active scheme requires a number of tags with known position placed on the floor and on the ceiling as minimum infrastructure. The passive scheme, instead, requires one tags grid placed on the floor or on the ceiling and a number of fixed reader (at least 4). Several simulations are carried out by the authors to evaluate the performance of the proposed schemes. In particular, they study the impact of parameters such as the density of the references tag grid, the number of the antennas (radiation elements), and the irregularity of transmission signal pattern quantified by a value that takes into account the maximum variation of the reader transmission. The scenario in which simulations are conducted is similar to a typical 40 X 8 X 8 feet container; 640 tags in the active scheme, and 8 reader with the addition of a tag grid for the passive scheme, are required to obtaining high location precision.

The approach introduced in the present paper is not comparable to the one previously cited for two main reasons: we show results obtained through experimental trials, while in [9] the performance evaluation of the proposal is simulated; furthermore, the experimental results shown to demonstrate the effectiveness of positioning schemes does not give enough details to allow carrying out comparisons. More specifically, our algorithm gathers incremental proximity information from regular grids of RFID active tags, by operating a suitable control over the RF-power of reader's interrogations. The main aim is to select tags that are actually the closest to the reader's location and, then, to average their positions and get a final position estimate.

3 Proposed Approach: Location Estimation through Proximity Information (LEPI)

In this section we propose a location estimation approach, called *Location Estimation through Proximity Information* (LEPI), that aims at assessing the position of a portable RFID reader device over a grid of RFID tags. More specifically, the reader's location is estimated as a weighted linear combination of the coordinates of those RFID tags that the portable reader recognizes as the nearest ones. We analyze the impact of different weighting functions, based on RF power measures, on the determination of the actually closest tags among those detected by reader interrogations.

The operation of LEPI is based on these intuitive observations: (i) the transmission power of scan requests emitted by the reader determines the size of the interrogation area and, consequently, the number of RFID tags that are able to respond; (ii) RFID tags that are physically closer to the RFID reader are more likely to respond to interrogations generated at lower transmission powers compared to the farther ones; (iii) by adding little increments to the transmission power of the scan requests, we are confident to always collect sets of RFID tags that are supersets of those collected with lower powers;(iv) by suitably averaging the coordinates of the RFID tags sensed as the nearest we can guess the actual reader's position.

We propose to deploy a two-dimensional grid of RFID tags, called *reference tags*, that are evenly spread over the area of interest, as shown in Fig.1. Each reference tag is associated to its own position on the grid either directly, by storing its coordinates into its memory, or indirectly, through a suitable mapping between IDs and positions provided by external information systems (e.g. a database available to the reader).

In Fig. 2 we describe how LEPI approach is executed. First, the reader generates a sequence of interrogations (i.e. of broadcast scan messages that wake up the reachable tags and query their IDs), each one transmitted with an increasing level of transmission power. We suppose to start interrogating at the lowest admitted transmission power and to stop when the highest allowed power is reached; thus actually increasing the reader detection range from the smallest to the largest available. During the interrogation phase, the reader associates to each identified tag the RF power of the first interrogation that woke it up (i.e. the lowest power transmitted by the reader that is capable to switch the tag on). We call such a value *identification power* and use it as an index of the proximity between tag and reader. Specifically, we assume that the lower the identification power, the closer the detected tag to the reader location (with a high probability). The interrogation cycle is stopped as soon as one of these conditions is met:

– (At least) a suitable, predefined number k of *near tags* has answered the interrogations, thus been detected. In case of detection of more tags than expected, then the first k tags are selected, based on the RSS of their answers as measured by the reader.

– The reader reached its highest transmission power. In such a case the currently detected tags are selected as *near tags*, whichever their number.

Finally, the reader's location is assessed as a linear combination of the positions of such *k near tags*, that can take into account the relevant *identification power* measures.

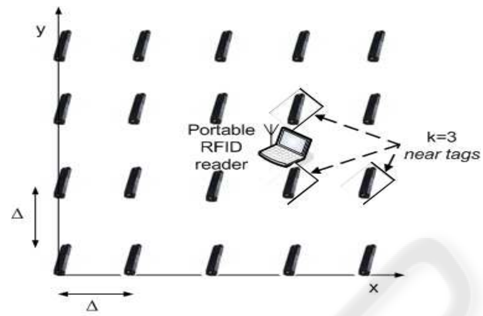

Fig. 1. LEPI configuration with RFID tags placed as reference points over a regular grid and a portable RFID reader.

The number *k* of the admitted *near tags* is a key parameter in the protocol design. Depending on *k*, the target position is evaluated as coincident with the reference tag that was detected first, if $k = 1$, or as a suitable point over the line or polygon whose vertexes fall on the *k near tags*, if $k > 1$. In order to average among such vertexes, we propose to distinguish among different weighting functions:

– **Center of mass** (CM), the simplest weighting method, consists in estimating the reader's location as the center of mass of the *near tags*' positions. In so doing, the same weight is given to all selected near tags.
– **Transmission power** (TX_pow), that assigns a weight to the selected *near tags* based on their *identification power*, defined above as the RF transmission power of the first interrogation that woke them up. Since we consider higher *identification power* measures as an index of longer distances between reader and tags, we choose to assign lower weights to tags associated to higher *identification powers*. Thus, we define weights as $w_i = \frac{1/IP_i}{\sum_{l=1}^{k} 1/IP_l}$, $i = 1, ..., k$ where IP_i is the identification power of the ith *near tag*.
– **Reception power** (RX_pow) considers a different RF power value associated to each near tag, called *reception power*; this is defined as the RSS of the response signal emitted by a tag following an interrogation, and it is measured by the reader antenna. Such a metric is complementary to the *identification power* we have used so far, since it takes into account the return link of the communication between reader and tags. To a first approximation, a higher value of *reception power* for a tag can be associated to a higher proximity to the reader, thus we can assign a

```
const int K; //predefined value of the near-tags
int tx_power = MINIMUM_TX_POW; //transmission power of the reader
Tags_array detected_tags;
while(detected_tags.length < K && tx_power <= MAXIMUM_TX_POW) {

        /*broadcast an interrogation with tx_power power
        and get the array of detected tags*/

        detected_tags = exec_interrogation(tx_power);
        tx_power += TX_POWER_STEP;
        //increase reader tx_power at a fixed step

 }
reader_position = average_positions(detected_tags);}
```

Fig. 2. Pseudocode description of LEPI algorithm.

higher weight to it. In formulas, the weight associated to the ith *near tag* is $w_i = \frac{RP_i}{\sum_{l=1}^{k} RP_l}$, $i = 1, ..., k$, where RP_i is its respective *reception power*.

By selecting the reference tags detected with low RF-power interrogations as the nearest to the reader, the LEPI approach translates closeness (in the radio signal propagation space) into proximity (in the actual - i.e. physical, space). However, there are many well known issues affecting the propagation of radio waves in indoor environments [8] that don't allow for direct correlation between RF-power and physical distance. Further, it is necessary to take into account effects like *false-negative* readings, i.e. unsuccessful detection of tags that are actually in the reader range, and *false-positive* readings, i.e. detection of tags that are far away from the reader and should fall out of its expected interrogation range [7]. Consequently, it is conceivable that the results of interrogations can bring to the selection of *near tags* that are not physically close to the target location; this leading to positioning errors. The LEPI approach tries to mitigate such an effect by selecting more than one *near tag*, thus distributing the impact of possible errors among them.

4 Experimental Results

In this section we will show performance results of the proposed approach, by analyzing some design parameters and by drawing a comparison with LANDMARC [3] (widely considered as a reference for location algorithms based on RFID systems). In order to carry out performance comparisons with LANDMARC, we implemented LEPI approach through an active RFID system, although cheaper passive RFID tags could fit as well to deploy LEPI solution.

We built a regular grid of RFID tags, as shown in Fig.1, in an indoor scenario consisting of a lecture room in which we added different pieces of furniture to simulate the required harsh environment. The grid is composed of 25 i-Q RFID tags produced by Identec Solutions [11], capable of up to $100m$ identification range, that are put at a fixed distance $\varDelta$ of $120cm$ on both axes. Such choice for $\varDelta$ was driven by the need to find a suitable compromise between the accuracy required by common indoor location services, that would ask for denser tags grids, and the operational costs of the location infrastructure, that increase when deploying thicker tag distributions.

The portable RFID reader, an Identec i-Card3 PCMCIA reader, was mounted on a laptop PC programmed to run LEPI and was moved on 32 positions, spanning the whole grid. The i-Card3 reader can generate interrogations with different values of RF transmission power, ranging between $-60dbm$ and $-10dbm$. In our implementation of LEPI, we started to send interrogation messages at the lowest available transmission power and increased it with a step of $1dbm$ a time, until either the predefined number k of near tags was detected or the highest transmission power was reached, as expressed in the LEPI formulation.

As for LANDMARC operation, we used two i-Port3 fixed RFID readers [11], that drove 8 antennas positioned at the edges of the grid of Fig.1. Differently from LEPI approach, LANDMARC is a tag-oriented location approach, thus we performed a further sequence of interrogations, by placing a RFID tag at the same positions in the grid we had previously selected to run LEPI, and leaving unaltered the remaining setup.

The positioning accuracy is assessed by determining the *location error*, defined as the Euclidean distance between the actual target location, i.e. the position of the RFID reader, and the one returned by the LEPI algorithm.

The first analysis we carried out is a comparison between LEPI and LANDMARC approaches, whose results are shown in Fig. 3. The reported curves represent the experimental cumulative distributions of the location errors of LEPI and LANDMARC algorithms, when $k = 4$ reference tags are selected as *near tags* and *center of mass* is used as the averaging function among *near tags*. We can observe that, under this configuration, LEPI attains lower location errors both on the average, with errors of about $130cm$, and with reference to higher percentages of experiments, like 90% of measurements, where errors not greater than $200cm$ are accomplished. Differently, LANDMARC experiences far higher errors, that compromise the use of the estimated positions. Such results, attained indoors for LANDMARC approach, are consistent with our previous analysis [2] and testify to the limitations of location methods based on direct RF power measurements in indoor scenarios. LEPI approach, that leverages on the detection of incremental proximity information, seems more capable of filtering out ”false near” reference tags.

A further analysis can be conducted about the optimal number k of *near tags* that shall be chosen by LEPI as the closest to the target location. In Fig. 4 we report the experimental cumulative distribution of location errors obtained when varying k between 1 and 5 and using the *center of mass* as the weighting function among the selected *near tags*. Although the curves intersect in some points within the area of low probabilities, we still can distinguish an interesting behavior with reference to higher probabilities, that correspond to a high degree of confidence on the experimental result. If, for instance, we focus on a probability of 0.9, we can notice that the use of either 3, 4 or even 5 *near tags* results to be effective in terms of location performance, differently from the cases of either $k = 1$ or $k = 2$. In other words, trusting in more reference tags to estimate the target location seems to allow for a reduction of positioning errors. We in-

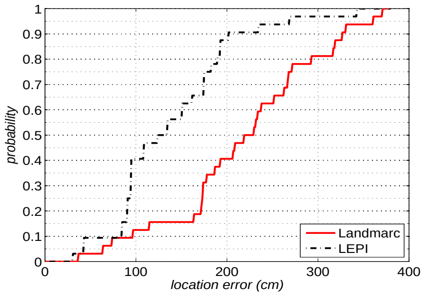

Fig. 3. Comparison of location error between LANDMARC and LEPI, with $k = 4$ reference points selected as *near tags*.

terpret this result by observing that incorrect selections of *near tags* can seriously affect location accuracy when a few tags are employed ($k = 1, 2$), while the use of more *near tags* can mitigate such effect.

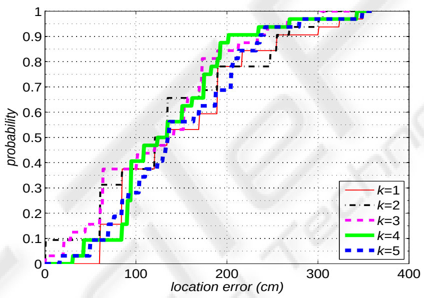

Fig. 4. Experimental cumulative distribution of location error when varying the number k of *near tags* in LEPI.

On the other hand, It is easy to argue that the higher the number of *near tags*, the longer is the time needed to complete localization procedures. In fact, a higher number of interrogations, emitted with increasing transmission power, is likely to be needed in order to detect higher numbers of tags. Our preliminary analysis on timing issues of LEPI approach, reported in Table 1, shows the average time needed to finalize positioning procedures with different numbers k of *near tags*, when using a fixed step of $1dbm$ for the reader transmission power. We can observe that the average location time increases with k, according to a non-linear law, and becomes as high as $12.41s$ when $k = 5$.

Starting from these results, we deduce that selecting the best value for *near tags* requires not only the evaluation of the achievable accuracy , but also an evaluation of the maximum tolerated delays associated to the location service of interest. Different policies and considerations can be conceived, based on special characteristics of each reader-oriented positioning application (e.g. degree of the reader's mobility, demanded location accuracy,...), in order to find the most suitable operational configurations. For instance, delay-sensitive location services, e.g. tracking of fast mobile devices, could not benefit from the higher accuracies achievable by using more *near tags*, since they would heavily be affected by the resulting delays. Due to space limitations, we leave more detailed studies on such an issue as a further research activity.

Table 1. Average time required to complete LEPI location when varying the number k of near tags.

k	1	2	3	4	5
time (secs)	0.68	1.35	4.29	8.55	12.41

Last point it is worth highlighting concerns the weighting functions among *near tags*. In Fig. 5 we analyze the positioning accuracy achieved when using the three averaging methods introduced in the previous section. More specifically, we reported location errors obtained in 90% of the conducted field measurements, for each weighting function and with different numbers of *near tags*. Clearly, abscissa values start from $k = 2$, instead of $k = 1$, since different weighting functions don't influence the results when a single *near tag* is selected. We can notice that the use of different weighting functions *does not* exhibit a plain impact on the location accuracy, when varying the number of *near tags*. Therefore, we cannot determine a general benefit coming from a particular solution. Based on such considerations, we can conclude that smart averaging policies, even based on RSS measures, cannot significantly help in improving the location performance; being this latter mainly driven by the correct selection of the *near tags*. Thus, it is preferable, and strongly suggested, to rely on the simplest of the proposed averaging solutions, that is the *center of mass*.

5 Conclusions

In this paper we conducted an analysis of location solutions based on RFID systems, providing a basic distinction between *tag-oriented* and *reader-oriented* approaches. Besides, we proposed a *reader-oriented* positioning algorithm called *Location Estimation through Proximity Information* (LEPI). We assessed the location accuracy of LEPI through an experimental campaign conducted indoor; it showed that such a positioning approach is more advantageous when compared to other *tag-oriented* solutions. We also detailed the impact of key project parameters affecting the resulting location accuracy, in order to determine the best operational conditions.

Future research perspectives comprise: (i) testing LEPI in a more dynamic environment with large mobile objects, (ii) the enhancement of the proposed localization technique toward tracking applications, where a stronger emphasis is put on *dynamic* positioning of moving people over a known area. In such a scenario, the time required

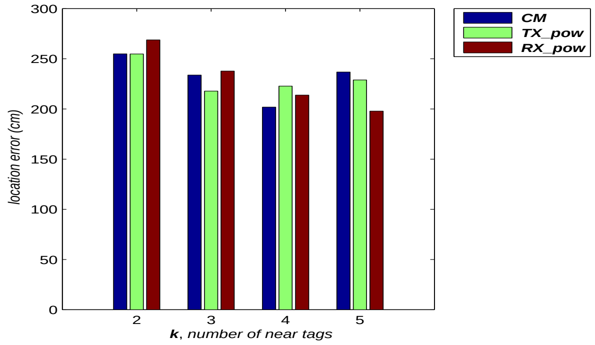

Fig. 5. Location error in 90% of positioning experiments when varying the number k of *near tags* and the weighting functions in LEPI.

to complete the positioning procedures plays a significant role too, besides location accuracy.

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