Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Technology 00 (2014) 000–000

Procedia Technology

www.elsevier.com/locate/procedia

Conference on Electronics, Telecommunications and Computers – CETC 2013

RFID alarm system and trajectory correction in paralympic athletics races

Nuno T. Almeida[a,b,*], Vitor Pinheiro[c]

[a]*INESC TEC - Institute for Systems and Computer Engineering of Porto, Rua Dr. Roberto Frias, 378, 4200-465 Porto, Portugal*
[b]*FEUP - DEEC, Department of Electrical and Computer Engineering, Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal*
[c]*FEUP, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, s/n, 4200-465 Porto, Portugal*

Abstract

In this paper is presented the work relative to the design of an aid system, for athletes with special needs in terms of vision. The system is based on Radio Frequency Identification (RFID) technology and serves to help visually impaired athletes. Relatively to Paralympic athletics competitions, the main goal is the elimination of current guide runners. The system is prepared to give a stereo audio alert, when a runner deviates from his lane central area. The paper presents the main components, namely, the RFID infrastructure and the mobile parts. Tests to tags, infrastructure setting and positioning functions are also presented.

Keywords: RFID; positioning; tags infrastructure; Paralympic athletics competitions; visually impaired athletes; alarm system; RSSI

1. Introduction

For athletes with visual impairments, the practice of some Paralympic sports activities often requires a specific kind of help. Concerning the athletics competitions, it is required the aid of guide runners for the guidance of those athletes. One objective of this work is to analyze how RFID technology may help, by providing useful audio information to blind athletes. The goal is to maintain the runner in his lane/normal trajectory. If this turns possible, the use of guide runners becomes no longer necessary. The work consists, therefore, in the design of an alarm system, based in RFID, providing stereo audio warnings when the athlete starts to deviate from his lane central area.

* Corresponding author. Tel.: +351-225-081-472; fax: +351-225-081-443.
E-mail address: nalmeida@inescporto.pt / nalmeida@fe.up.pt

In this way, the athlete can take early trajectory corrections, before reaching respective lane borders.

The use of RFID technology, in localization processes, is not completely new and diverse examples, as in [1,2], can be found in the literature. Nevertheless, a specific use of this technology to aid visually impaired citizens is a little rarer, but examples, as in [3,4], can still be found. The RFID technology is, also, often used in the object localization topic, originating interesting new advances [5]. Analytical approaches, used in RFID based applications, is also a relevant and pertinent topic [6].

Regarding the paper organization this is the following. In section 2 is introduced the system concept, including a brief description of the athletics tracks and the requirements to be met by the system. The main components of the system are here identified, namely, the tags infrastructure and the mobile part (to be carried by the athletes). In section 3 is detailed the infrastructure, presenting the analysis made, in order to get the appropriate values for the transversal and longitudinal distances, between tags. In section 4 are shown the algorithms of the system and the important zone detection functions, which allow the trigger of the alarms. In section 5 are presented the conclusions.

2. System concept

The general concept of the system takes into account the usage scenario of an athletics track and the equipment of an athlete. Concerning the outdoor athletics track, this is 400 meters long (inside perimeter) and, normally, has 8 individual lanes, as shown in Fig.1 (a). Regarding the width of each lane this is 120 cm wide, with a separation of 5 centimeters between adjacent lanes.

As described ahead, the system concept assumes lanes containing sets of RFID tags and mobile individual readers, which use the received power to support the orientation purpose. However, the system will not rely in a sort of triangulation of athlete's position, due to expected irregular power spatial distribution of the tags. Instead, the system will focus in the estimation of differentiated transversal lane zones, occupied by the runner.

With this goal, the intended configuration, in each individual lane, includes a security zone and four alarm sub-zones, as shown in Fig.1 (b). Hence, the main objective is to give audio alerts to a runner, in function of his transversal zone position. As shown in Fig.1 (c), the audio alerts have two intensities depending on the estimated alarm sub-zone. To ear and distinguish between left and right side deviations, each athlete carries a stereo headset.

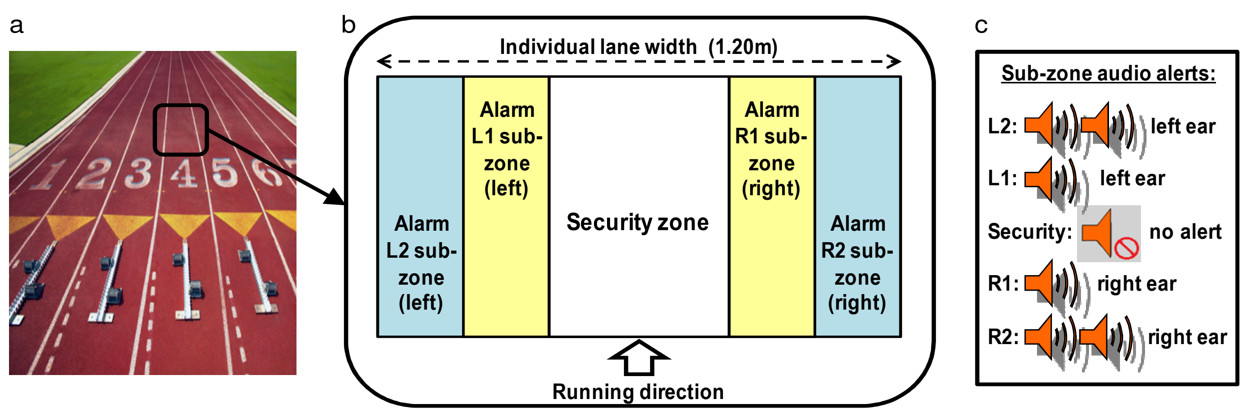

Fig. 1. (a) An athletics track with respective individual lanes; (b) Security zone and alarm sub-zones intended in each lane; (c) Each runner has a system delivering individual stereo audio alerts, having two intensities depending on estimated alarm sub-zone.

In relation to the normal equipment of an athlete, this comprises a racing singlet, shorts and sneakers shoes, being the total weight an important aspect. As described ahead, some system components are assumed to be embedded in the equipment, being the remaining kept to minimum size and weight. In a concise way, and taking into account the usage scenario and the intended characteristics, the main requirements of the system can be listed as the following:

- Detection of runner's position (longitudinal and transversal zones), inside his lane;
- Intuitive alerts to the athletes;

- Portable and lightweight system;
- Adaptation to current athletics tracks.

Attempting to fulfill above mentioned requirements, the system conception divided its components into two main parts: the system infrastructure and the system mobile part.

2.1. System infrastructure

The infrastructure is composed by sets of active RFID tags, located at track surface level (slightly buried), with a certain spatial distribution. The choice of active tags, versus passive ones, is due to their wider range of action and faster response time. In Fig. 2, is shown the initial configuration defined for the tags' sets (one set for each lane), being the tags organized into left and right ones.

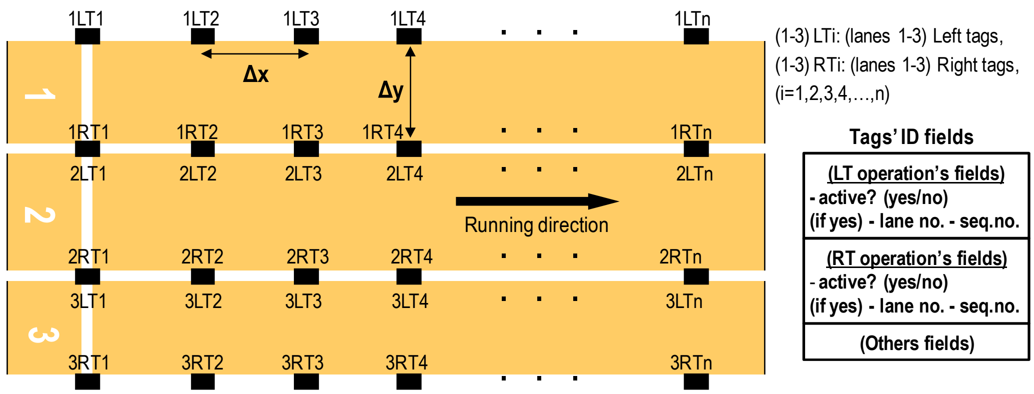

Fig. 2. Initial infrastructure configuration of RFID tags' sets (one for each lane); tags are mainly divided into left and right one types, having the respective identification; finding suitable longitudinal (Δx) and transversal (Δy) distances is an issue of the system infrastructure characterization.

The tags have also unique identifiers, providing, among other, information about the lane number, disposition in the lane (left/right tag or other) and a sequence number, relatively to the starting line. Suitable longitudinal (Δx) and transversal (Δy) distances, between tags, were initially unknown but, as described in section 3 (Infrastructure characterization), the developed work included radio frequency (RF) analysis, leading to a justified choice for it.

2.2. System mobile part

Regarding the mobile part of the system, to be carried by a runner, this is composed by three components. They are, namely, the RFID readers, the processing device and the stereo headset. As depicted in Fig. 3, the RFID readers are assumed embedded in the athlete's shoes, communicating with the processing device through a Bluetooth connection. As seen in other systems [7], a Bluetooth link is also used to make the communication between the processing device and the stereo headsets.

Regarding the sneakers' embedded RFID readers, besides reading the data of vicinity tags they also measure respective received powers, setting the Received Signal Strength Indicator (RSSI) information for each readied tag. Reading sets are triggered by the contact of the shoes with the floor, as this corresponds to the most stable position of the readers (when considering the strong speed variation of feet movement). The sample rate depends, then, on the ratio between runner's velocity and his footstep size. Assuming a footstep average of 1.5 m, velocities between 4m/s and 10m/s lead to sample rates of 2.7 to 6.7 sets per second, thus sufficient to the processing of audio alerts.

All the gathered information is, then, communicated to the processing device, which makes its analysis, by way of specific algorithms, particularly developed to the effect (algorithms are referred in section 4). The processor's main output is the estimate of runner's position in terms of transversal zone (security or alarm sub-zones). This estimate, depending on its zone value, triggers, or not (if is the security zone), a specific audio signal which is transmitted to the stereo headphones.

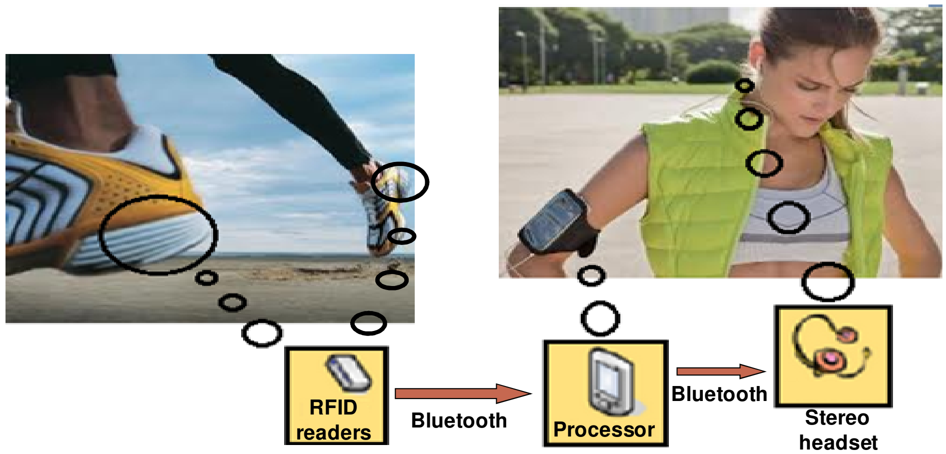

Fig. 3. The mobile part of the system is carried by the athletes; for each runner, there is a set composed by RFID readers (embedded in the sneakers shoes), a processing device and a stereo headset; components of the set communicate by Bluetooth.

3. Infrastructure characterization

As mentioned before, considering the RF power characteristics of the tags, in principle, is possible to have an estimate of the athlete's zone position, inside his lane. Nevertheless, to accomplish this, besides the physical infrastructure presented in the previous section, the determination of adequate transversal and longitudinal distances, between tags, is crucial. Therefore, over a set of RFID active tags (SYTAG245-2S model, operating at 2.45 GHz), several tests were carried out, in order to get information relative to their power spatial distribution.

3.1. Transversal distance between tags

One result of above referred analysis is shown in Fig. 4 (a). Here, there is one tag positioned in the left side of a lane (tag LTi) and other in the right side (tag RTi). This figure shows the average measured power (in mW), noting that most power is within a distance of 40 cm of respective tag. As the initial objective is a reduced RF power in the central zone of individual lanes, and a considerable one in the lateral zones, a good solution for the transversal distance is then Δy = 120 cm. As depicted in Fig. 4 (b), this leaves a central zone with approximately 40 cm, where received power, from any tag, presents a low value.

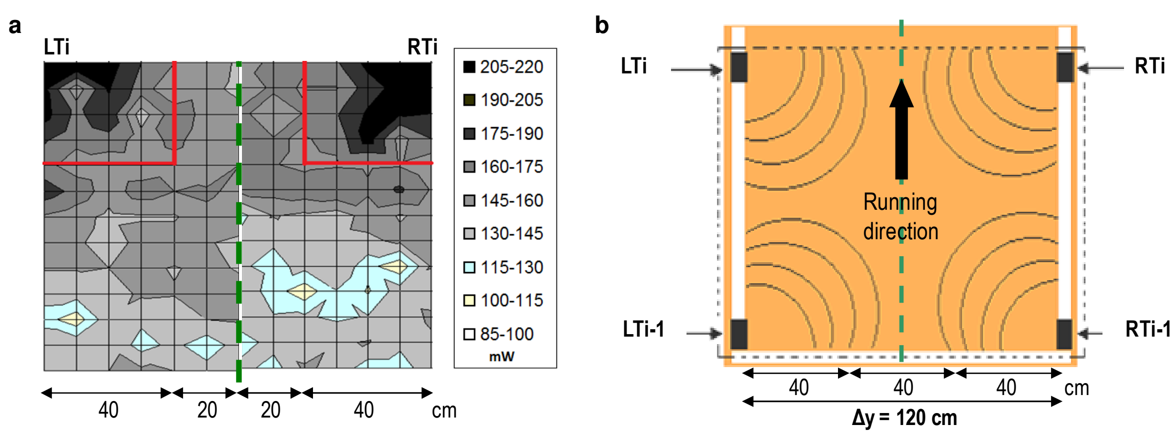

Fig. 4. (a) Power spatial distribution of tags positioned in the left (LTi) and right (RTi) sides of a lane; (b) the adoption of a transversal distance (Δy) of 120 cm, leaves a central zone with 40 cm, presenting relatively low powers.

3.2. Longitudinal distance between tags

Assuming, then, a Δy = 120 cm, a similar analysis was done to evaluate an adequate longitudinal distance (Δx) between tags. This analysis involved 2 tags in the left side of the lane (LTi and LTi-1) and 2 others in the right side (RTi and RTi-1). Figure 5 shows the results obtained for Δx = 120, 100 and 60 cm. It can be seen that a Δx = 120 cm, or 100 cm, presents significant power gaps in the lateral zones of the lane. For a Δx = 60cm still exists a rather small gap, but this is an acceptable compromise, between the selected longitudinal distance and the total number of tags in the system.

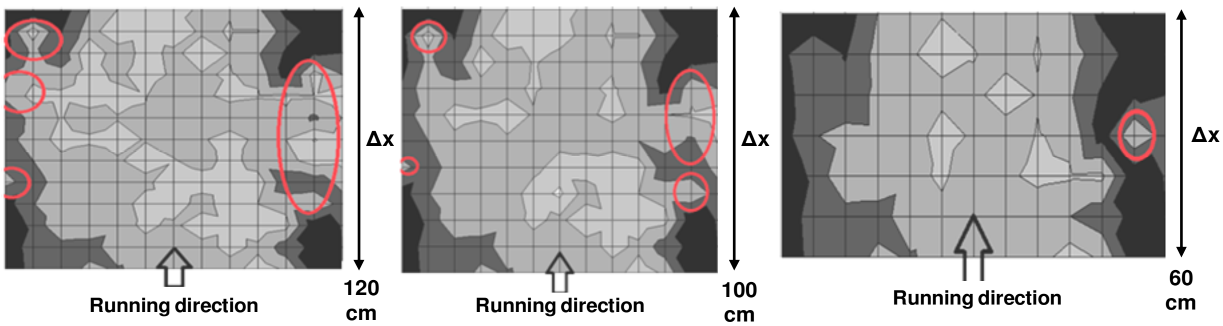

Fig. 5. Spatial distribution of maximum received power, considering one tag in each corner and 3 longitudinal distances (Δx=120, 100 and 60cm)

With this settlement, for suitable transversal and longitudinal distances, is then defined a sub-structure of tags, named *quadrant*, which will be repeated along each racing lane. As depicted in Fig. 6, a quadrant is composed by 4 adjacent tags (2 in each side of a lane), with Δx =60 cm and Δy = 1.2 m distances, playing a determinant role in the estimation of the alarm zones. With a Δy = 1.2 m, tags in the lane edges can also operate as left and right one types.

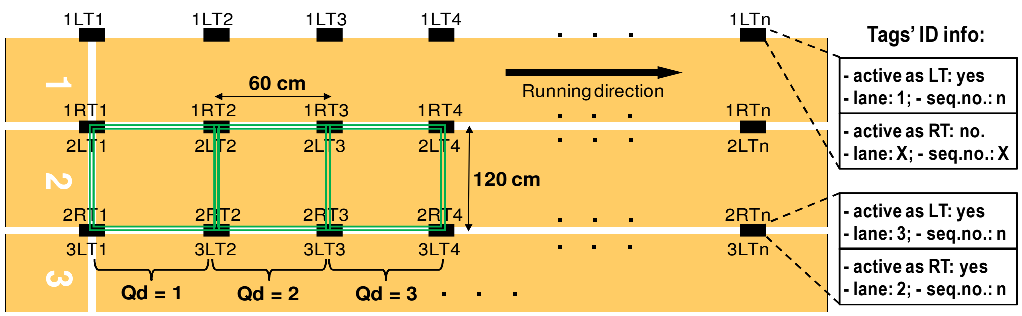

Fig. 6. Each quadrant (Qd) is composed by 4 adjacent tags (2 in each side of a lane) and they are sequentially numbered along the lanes.

4. Algorithms and zone estimation functions

4.1. Main algorithm

To perform the necessary tasks, related with the alarm function and the ultimate trajectory correction, the system implements a main algorithm, as shown in Fig. 7. This algorithm fundamentally establishes the general flow of the information inside the system. With that purpose, on a runner footstep basis (i.e., sample rates between 2.7 and 6.7 Hz), the RFID readers obtain the tags information and the respective RSSI values. In the following, that information is passed to the processor, through a Bluetooth link, to further analysis. The main algorithm makes, then, calls to two other algorithms which estimate, sequentially, the quadrant and the transversal (security/alarm) zones. In fact, based on the readings obtained by the RFID readers, the processor executes, in a 1st stage, the calculus of the actual quadrant, where the athlete is (that is, his approximated longitudinal position). As explained just ahead, the quadrant tags will serve, in a 2nd stage, to estimate the more sensible, and important, transversal zone position of the athlete.

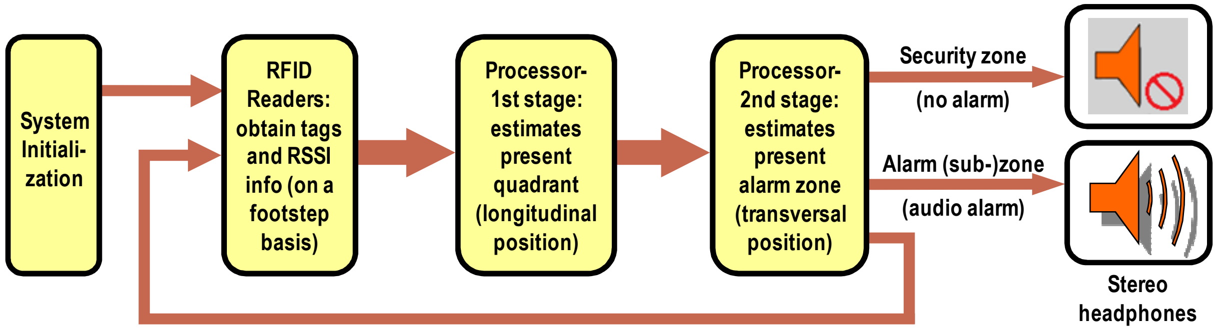

Fig. 7. System's main algorithm: it involves the RFID readings and the processor calculations; these last include the *quadrant* and the alarm zone estimation algorithms.

4.2. Zone estimation functions involving quadrant tags

After quadrant detection/selection, it becomes necessary the subsequent estimation of the alarm zone (transversal position). As said before, this implies a clear identification of the security zone and the left/right alarm sub-zones. For this estimation, considering only the individual RSSI absolute values is visibly insufficient. In fact, due to several variations in the received power, that approach doesn't provide accurate values. Hence, to achieve better estimates, the idea is to involve all tags, pertaining to the estimated quadrant, in the calculus process.

So, to obtain a better metric for the estimation process, it were defined some mathematical/logical functions, to be executed with the available quadrant information (tags' type and RSSIs). The alarm zone functions are, then, composed by a power metric function and by a side deviation indicator. For quadrants with 4 tags, the first defined power functions are based in the RSSI variance, as shown in equations 1 and 2 below, where (for quadrant *i*)

- Zd_4 : zone detection power metric for quadrants with 4 tags (in mW^2),
- p_{LTi} and p_{RTi} : RSSI values of, respectively, left tags *i* and right tags *i* (in mW),
- S_{Tmax} : side type (left or right) of tag corresponding to maximum RSSI of $\{p_{LTi}\,;\,p_{LTi+1}\,;\,p_{RTi}\,;\,p_{RTi+1}\}$,

$$(Zd_{4a}, S_{Tmax}) = (\mathrm{var}\,(p_{LTi}\,;p_{LTi+1}\,;p_{RTi}\,;p_{RTi+1}), S_{Tmax}) \tag{1}$$

$$(Zd_{4b}, S_{Tmax}) = \left(\mathrm{var}\left(\frac{p_{LTi}+p_{LTi+1}}{2};\frac{p_{RTi}+p_{RTi+1}}{2}\right), S_{Tmax}\right) \tag{2}$$

In Fig. 8 (a) and (b) are depicted, respectively, the mapping of the results obtained by Zd_{4a} and Zd_{4b} functions.

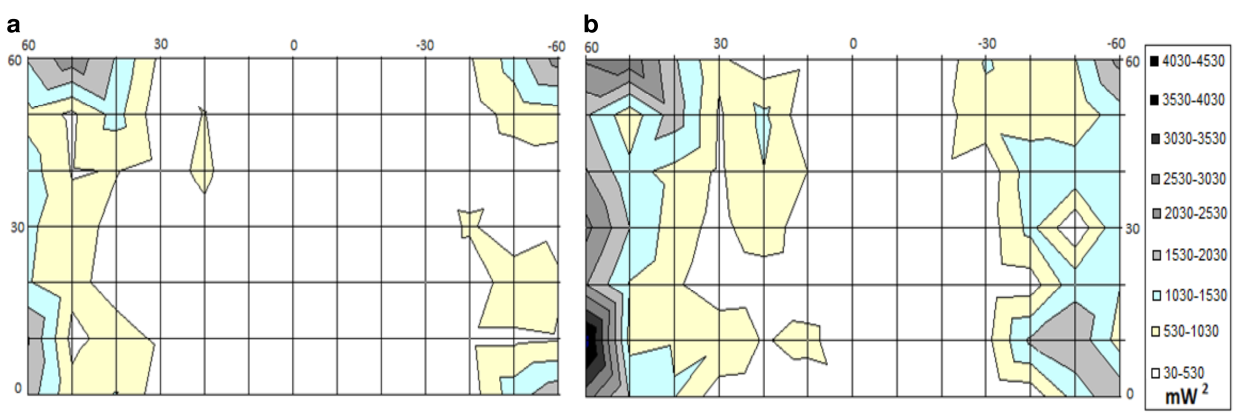

Fig. 8. Mapping of zone detection power metrics, in a 4-tags quadrant: (a) variance considering RSSI individual values (Zd_{4a} function); (b) variance considering right and left tags RSSI mean values (Zd_{4b} function).

4.3. Zone estimation functions in quadrants with central tags

Despite the bearably sufficient result of Zd_{4b} function, is possible to get an improvement if more tags are added to the quadrant. Accordingly, central tags are added to the lanes, forming quadrants with 6 tags. In Fig. 9 (a) and (b) is shown, respectively, the 6-tags quadrant infrastructure and the new spatial distribution of maximum received power.

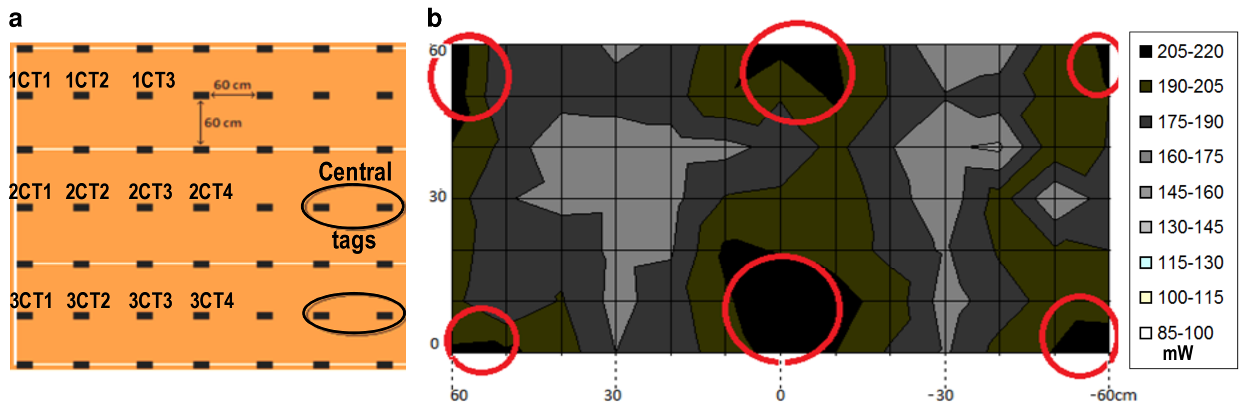

Fig. 9. (a) Infrastructure configuration by adding central tags in the lanes; (b) Spatial distribution of maximum received power, considering quadrants with 6 tags (positions indicated by the red circles).

The inclusion of central tags in the infrastructure permits the upgrade of the zone estimation functions, since more information is now available. One of these new functions calculates the variance of lateral tags (as in equation 2) and divides this result by the maximum RSSI value of central tags, belonging to the quadrant in analysis. The calculus of this function is shown in equation 3, where (for quadrant *i*)

- Zd_6 : zone detection power metric for quadrants with 6 tags (in mW),
- P_{CTi} : RSSI values of central tags *i* (in mW),

$$\left(Zd_{6a}, S_{Tmax}\right)=\left(\frac{\operatorname{var}\left(\frac{p_{LTi}+p_{LTi+1}}{2};\frac{p_{RTi}+p_{RTi+1}}{2}\right)}{\max\left(p_{CTi};p_{CTi+1}\right)}, S_{Tmax}\right) \tag{3}$$

A second function (Zd_{6b}) executes the same calculus as equation 3 but, with the information relative to the expected spatial distribution of maximum RSSI values (diagram of Fig. 9 b), and knowing corresponding tags' types, the final result depends on the output of a certain logical function as follows:

- If, quadrant tag with maximum RSSI = central tag, then Zd_{6b}= 0 (corresponds to a security zone estimation);
- If, quadrant tag with maximum RSSI = lateral tag, then Zd_{6b}= max (Zd_{6a}; *k*), where *k* is a tunable parameter.

For Zd_{6b}, a value of 3 is set to parameter *k*, after some experiments with different values. In view of that, the definition of the alarm zones, in function of Zd_{6b} and S_{Tmax} outputs, is:

- Security zone (any S_{Tmax}): $0 \le Zd_{6b} \le 2$;
- Alarm sub-zones L1 and R1: $2 < Zd_{6b} \le 4$, L1 if S_{Tmax}=left, R1 if S_{Tmax}=right;
- Alarm sub-zones L2 and R2: $Zd_{6b} > 4$, L2 if S_{Tmax}=left, R2 if S_{Tmax}=right.

In Fig. 10 (a) and (b) are shown the mapping of the results relative to Zd_{6a} and (Zd_{6b}, S_{Tmax}) functions. The outputs achieved by Zd_{6a} and Zd_{6b} functions are, as expected, more satisfactory than the ones involving only quadrants with 4 tags. But, from these two functions, and considering the purposed goal, the output reached by Zd_{6b} stands out as a fairly reasonable solution, in order to provide a reliable alarm to the athlete, thus, enabling his trajectory correction.

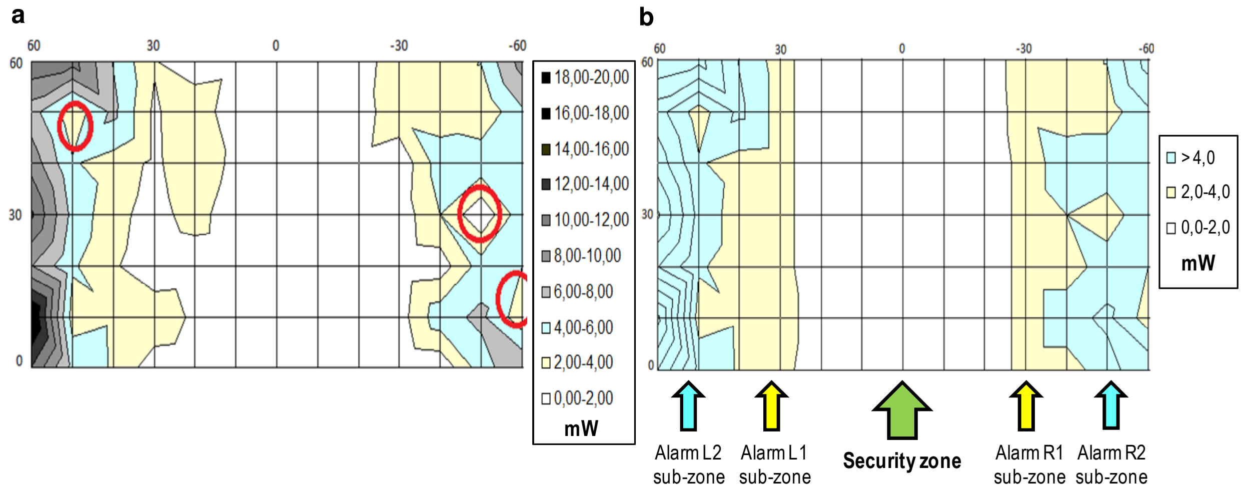

Fig. 10. Mapping of improved power metrics, in a 6-tags quadrant: (a) results of Zd_{6a} function; (b) results of Zd_{6b} logical function (k=3) combined with S_{Tmax} (side deviation) results, thus allowing a fairly reasonable match to defined security and alarm sub-zones.

5. Conclusions

In this paper, it was presented the work related with the conception and the definition of an aid system for visually impaired athletes. The usage scenario is the athletics tracks and the sprint events. The main goal is to enable the participation of blind athletes in those races, without the help of guide runners. It was shown that this system, based on RFID technology and using active tags fixed on the track surface, can provide valuable information about the actual position of the athlete, inside his lane. With that information, audio alerts can be triggered when the athlete diverges from his lane central zone and, subsequently, a trajectory correction can be made.

The developed work shows the role of the system infrastructure, being the concept of quadrant of primordial importance. In this aspect, the determination of appropriate values for the transversal and longitudinal distances between tags was crucial. Relatively to the acquisition and processing devices, these are carried by the runner, with a special focus in the RFID readers which are assumed embedded in the sneakers shoes. It was also stressed that the estimation of the transversal position requires a special processing of the received powers. In that sense, they were defined several zone detection functions and respective diagrams presented.

A lot of work remains still to be done, particularly in the full system assessment phase, but an important notion is, for now, achieved. In fact, as exemplified by the results of Zd_{6b} function, the followed approach seems to be capable of a coherent and adequate response, to the proposed challenge.

References

[1] Sanpechuda T, Kovavisaruch L. A review of RFID localization: Applications and techniques. In: Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, ECTI-CON 2008, 5th International Conference on; 2008.

[2] Xavier J, Abreu PH, Reis LP, Petry M. Location and automatic trajectory calculation of mobile objects using radio frequency identification. In: Information Systems and Technologies, CISTI, 6th Iberian Conference on; 2011.

[3] D'Atri E, Medaglia CM, Serbanati A, Ceipidor UB. A system to aid blind people in the mobility: A usability test and its results. In: Systems, ICONS '07, Second International Conference on; 2007.

[4] Neiva JPB. Localização e orientação "indoor"com recurso à tecnologia rfid. In: Neiva JPB, editor. Master Thesis in Electrical and Computer Engineering. Faculty of Engineering of University of Porto; June 2012.

[5] Po Yang, Wenyan Wu, Moniri M, Chibelushi CC. Efficient Object Localization Using Sparsely Distributed Passive RFID Tags. In: Industrial Electronics, IEEE Transactions on (Volume:60, Issue: 12); Dec. 2013.

[6] Abdelhalim EA, Ei-Khayat GA. A survey on analytical approaches used in RFID based applications. In: Computer Applications Technology, ICCAT 2013, International Conference on; 2013.

[7] Almeida NT, Ribeiro E. Linux software and bluetooth: a formula to improve accessibility by using interactive voice response systems. In: Software Development for Enhancing Accessibility and Fighting Info-Exclusion, DSAI 2009, 2nd International Conference on; 2009.