Effects of Antenna Characteristics in RFID Systems for Positioning Purposes

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Abstract

Radio Frequency Identification (RFID) is a wireless system designed to identify the presence of objects attached by tags. In recent times, RFID is also used for positioning purposes. We show a scenario of wireless propagation observed by eight antennas with different polarization located in different positions. In this way, the antenna characteristics, i.e. the polarization and diagram radiation of the antennas will play a significant role in producing electromagnetic field in the region. In this work we will use the fingerprinting procedure, with this we produce some data bases containing the electric field received by RFID readers if we located the RFID tag in certain position in region of interest. In this work, two cost functions are proposed, which are to be minimized for determining the position of the tag.

Keywords: RFID, identification, positioning, wireless, antenna, polarization, radiation diagram.

1 INTRODUCTION

Nowadays Radio Frequency Identification (RFID) becomes a mature application of wireless technology [1]. RFID is ubiquitous, is used for different purposes [2]. An emerging application of RFID is positioning of objects, especially mobile robots [3, 4, 5] and communication networks [6, 7, 8]. For indoor propagation problem, RFID based positioning systems are preferred than the GPS based counterpart [9], due to the shadowing problem of the satellite signals. Other indoor positioning systems are given in [10, 11]. In [12,13] RFID systems are used for accurate positioning problems in indoor propagation. Most of publications concerning with wireless propagation problems used statistical data evaluations [5, 14, 15], and some few other used simple deterministic approach [16, 17, 18]. In this work we would like to observe the effects of polarization/orientation and diagram radiation of the antenna in an indoor positioning system. For estimating the position we use the fingerprinting approach. To produce the data base, a scenario in a free space region with dimension of 6 m x 6 m is observed. Around the region we set up eight antennas in different known positions and different polarization. The tag will be moved around the region.

2 BASICS OF WIRELESS POSITIONING

There are three important signal characteristics can be used for the positioning purposes; the received signal strength (RSS), the angle of arrival (AOA) and the time of arrival (TOA) [19, 20]. With these characteristic quantities we can deduce information about the position of the tag attached on an object.

To implement the method angle of arrival (AOA) we need directional antennas. AOA methods are the core of direction finding (DF), which has been used for years to locate illegal transmitters or for tracking wild animals that are tagged with tiny transmitters. It requires no cooperation from the target, and any type of signal can be used, including continuous wave (CW). It also is used over wide frequency bands and ranges—from high frequency (HF) through microwave and from direct true line-of-sight to long communications distances propagated through the ionosphere. AOA is a principle component in a radar system. Using radar, only one fixed station is required to determine the location of a target in two or three dimensions. The two methods of AOA and time of flight (TOF) are employed. When using AOA alone, at least two fixed terminals are required, or two separate measurements by a single terminal in motion.

TOA (time of arrival) and TDOA (time difference of arrival) methods use relationships based on distances between a mobile station and a number of fixed terminals to determine the position coordinates of the mobile target. Data for distance estimations are derived from the arrival times of radio signal epochs at one or more receivers. The TOA method uses the transit time between transmitter and receiver directly to find distance, whereas the TDOA method calculates location from the differences of the arrival times measured on pairs of transmission paths between the target and fixed terminals. Both TOA and TDOA are based on the TOF principle of distance measurement, where the sensed parameter, time interval, is converted to distance by multiplication by the speed of propagation. In TOA, location estimates are found by determining the points of intersection of circles or spheres whose centers are located at the fixed stations and the radii are estimated distances to the target. TDOA locates the target at intersections of hyperbolas or hyperboloids that are generated with foci at each fixed station of a pair.

In applying RSS we use the condition that, signal strength at a receiver decreases as distance from the transmitter increases. If the relationship between signal strength and distance is known, analytically or empirically, the distance between two terminals can be determined. When several base stations and a target are involved, triangularization can be applied to determine the target's location. RSS has several advantages over the TOF methods. It can be implemented on an existing wireless communications system with little or no hardware changes. All that's needed is the ability to read a RSSI (received signal strength indicator) output that is provided on virtually all receivers, and to interpret the reading using dedicated location estimation software. Thus location capability can be added to a wireless system for very low incremental cost.

On the other hand, there are specific problems in implementing location awareness with the RSS method. Because of large variations of signal strength due to interference and multipath on the radio channel, location accuracy is generally less than what can be achieved using TOF methods. Propagation is location/environment specific, and system software usually has to be tailored to the place where the system is being used. Often, as will be shown later, a specific database must be created for a given location. In order to achieve a useful accuracy in a location system, many more fixed, or reference terminals, are required than the minimum number needed for triangulation. Orientation of a target as well as its location related to nearby objects will have an effect on the location estimation.

There are two basic classes of systems that use RSS to estimate location: those that are based on known radio propagation analytic relationships (the so-called proximity), and those that involve searching a database that is composed of measured signal strengths in a location specific survey. The latter class is often referred to as fingerprinting.

In this work we restrict our observation to RSS with fingerprinting. The data base can be produced by means of calculation or by measurements. Specially in calculating the received power as data entry in the data base several methods ranging from simplest analytical methods to sophisticated numerical hybrid methods can be used.

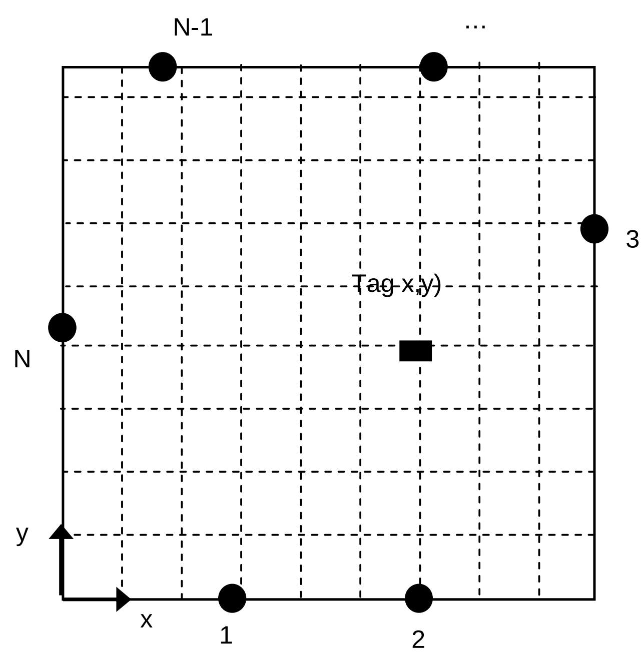

Fig. 1 Positioning of tag (object) by means of N receiver antennas.

Fig. 1 shows a grid structure giving possible locations in which data on received power is stored in a data base. Certainly, the accuracy of the later positioning procedure can be improved by taking a finer grid structure with the cost of bigger data base and consequently more intensive calculation for all steps in positioning procedure.

Having data base containing received power information in each chosen reference points, the next goal is how to determine a point if some received power information is given. This problem can be solved by a simple search method or by complicated but more efficient optimization methods. Therefore, it would be two challenges in this step, which optimization method should be taken and what kind of cost function should be used. In this work we used the brute force search method and the following least square cost functions

$$F = \left(\sum_{j=1}^{N} \left(P_{actual} - P_{x,y,DB} \right)^2 \right)^{1/2} \tag{1}$$

Or

$$F = \left(\sum_{j=1}^{N} \left(2 \frac{P_{actual} - P_{x,y,DB}}{P_{actual} + P_{x,y,DB}} \right)^2 \right)^{1/2} \tag{2}$$

$P_{x,y,DB}$ is the power received in point x,y stored in data base, P_{actual} is a given power, its location must be determined, *N* is the number of antenna receivers used for positioning problem.

3 ANTENNAS IN RFID

As one of the most important part of wireless systems, antennas play a significant role in tailoring the overall performance of the RFID. Designing of antennas depends on the specifications given by the system in which the antennas embedded. Important data is certainly the frequency region of the antenna. In this work we will restrict our problems to UHF region 900 MHz and use dipole antennas with length a half of wave length [21]. In this work we use the method of moment [21] for all antenna structures including the tag. The received power will be calculated by means of induction of the field in the remote structure, i.e. in the scattering matrix form would be S_{21}.

4 SIMULATION RESULTS

For a detail observation we make use a special case, a region 6 m x 6 m. We would like to determine the exact position of the tag inside this region. Fig. 2 shows the tag at the position (x,y) in the region and around it there are eight antennas with different positions and orientations (polarizations).

The table I gives information about the complete position and polarization of each antenna. These antennas receive signals sent from the tag and based on the received signals the actual position of the tag should be predicted as accurate as possible.

Table I Locations and polarization of receiving antennas

Antenna	x[m]	y[m]	polarization
1	2	0	X
2	4	0	Z
3	6	2	Z
4	6	4	Y
5	4	6	Z
6	2	6	X
7	0	4	Y
8	0	2	Z

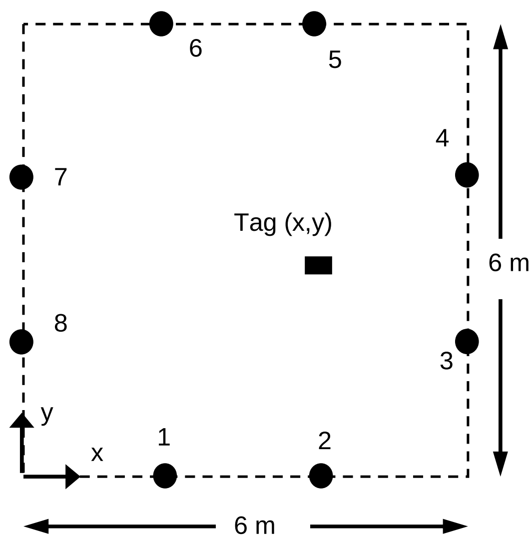

Fig. 2 Observed scenario with eight RFID readers around it.

For the sake of simplicity we restrict our attention for cases the antennas and tag are located on the same z level, and no other structures, including walls, floor and ceiling, exist.

At first, we calculate the received signals if the tag is oriented in x direction, i.e. the tag antenna has x polarization. With the variation of the position of the tag in the observed region we get certain patterns of received power level, Fig. 3 shows the patterns. The pattern for antenna 1 and 6 is identical, also antenna 4 and 7.

For x polarization we see due to orthogonal polarization between tag and ant 4 at the position y = 400 cm, just little power will be received. The similar condition can be also found for antenna 7.

The received power by antenna 1 and antenna 4 forms certain pattern that shows constructive and destructive superpositions.

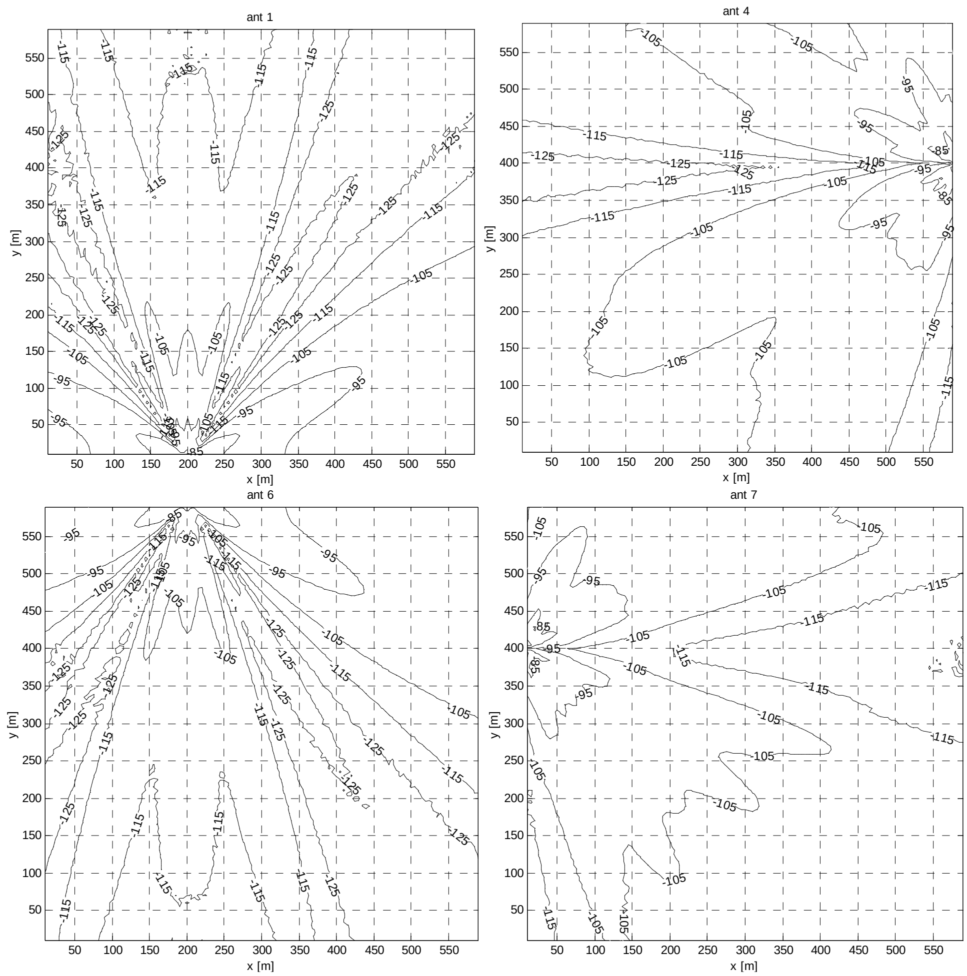

Fig. 3 Received signal in logarithmic scale as the tag moved, case x polarization.

For tag polarization in z direction, we have the result as depicted in Fig. 4. For z polarization we see a regularity of the received power due to the fact that in this case the radiation diagram is omnidirectional. For the next observation , we concentrate in the case x polarization, as depicted in Fig. 3.

The received power level is stored in a data base as reference for next observation. The data base consists of 20 x 20 locations which are distributed in x = 10 cm, 40 cm, .. 580 cm and y = 10 cm, 40 cm .. 580 cm coordinates. For each point, four received power for antenna 1, 4, 6 and 7 are stored.

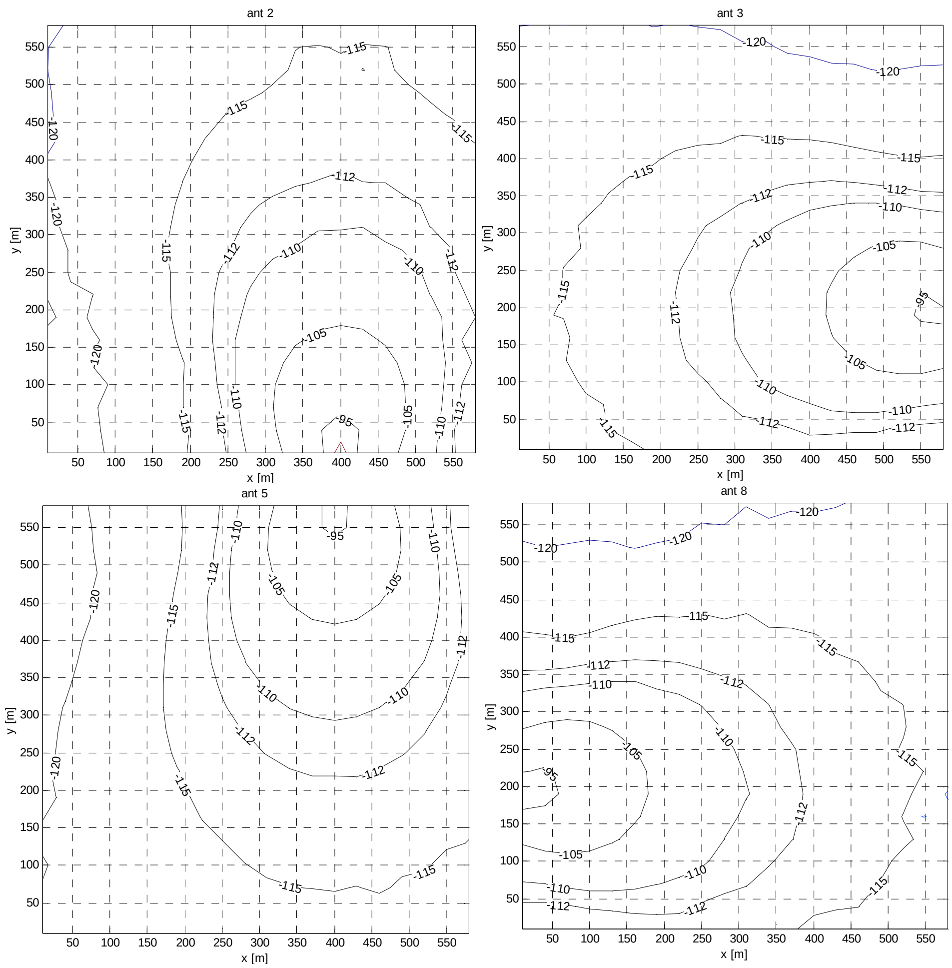

Fig. 4 Received signal in logarithmic scale as the tag moved, case z polarization.

As first observation we get from calculation or measurement the received powers in five different positions (table II)

Table II Received power level in decibel

Position	E1	E4	E6	E7
1	-110.2136	-118.5759	-119.3340	-96.4848
2	-113.9358	-115.8192	-108.9555	-97.3702
3	-110.6494	-112.7481	-108.5639	-99.2522
4	-113.9911	-109.3802	-108.9351	-104.7876
5	-110.0855	-106.1732	-120.0083	-109.9018

Applying the fields given in table 2 into the cost functions and using the data base stored before, we will get the values in entire region and try to find the minimum, if possible the global minimum. Fig. 5 shows the results for position 1 and Fig. 6 for position 2.

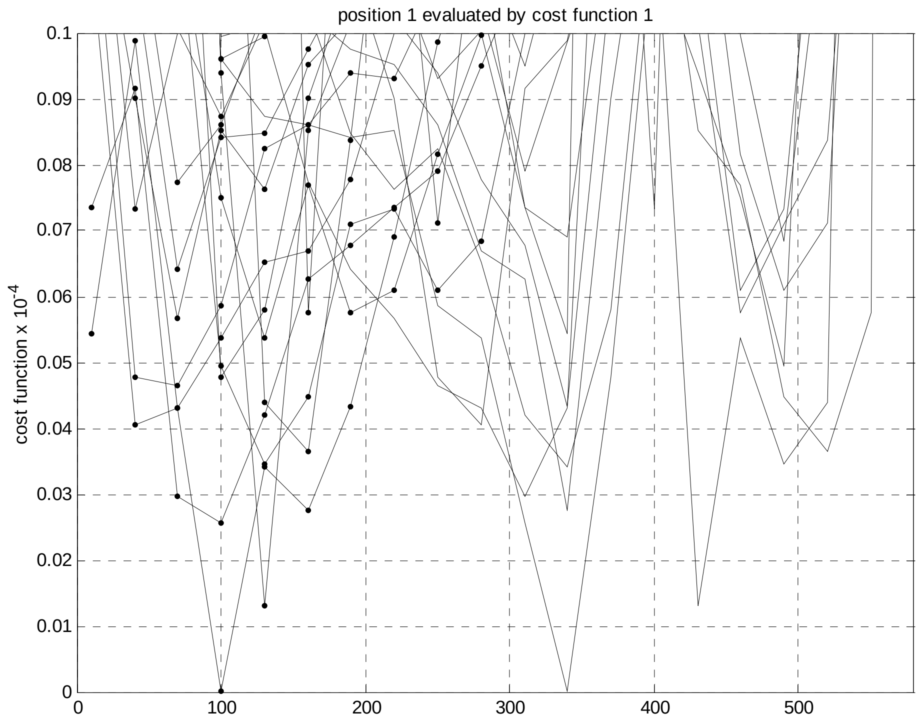

Fig. 5 Values of cost function 1 for position 1 (the horizontal axis is for x[cm] solid point y [cm]).

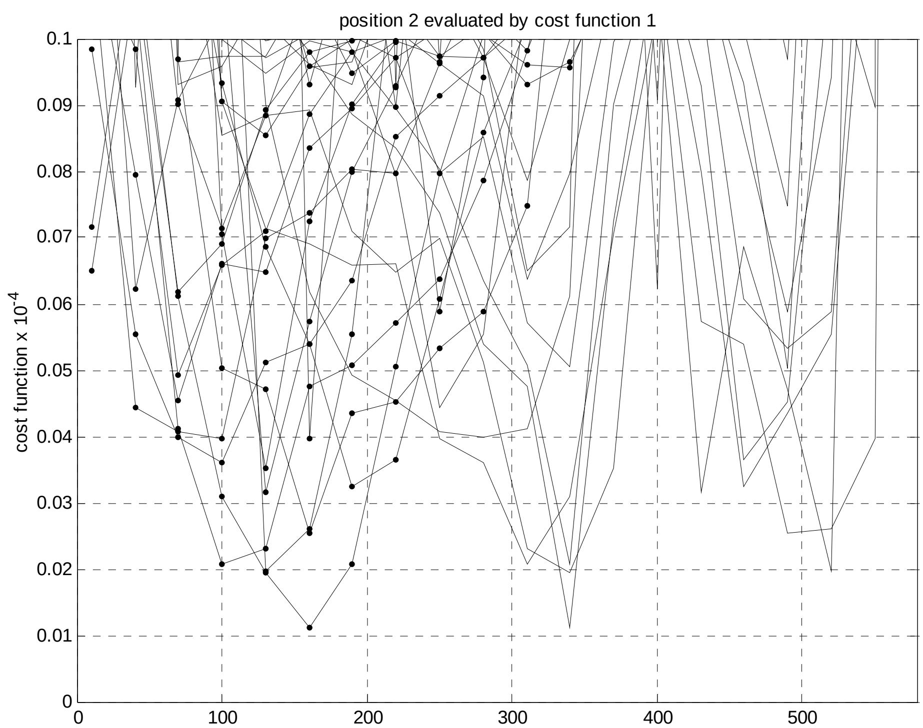

Fig. 6 Values of cost function 1 for position 2 (the horizontal axis is for x[cm] solid point y [cm]).

We see the global minimum for position 1 (Fig. 5) is reached by the pair x = 100 cm and y = 340 cm, with the value for the cost function of zero. Fig. 6 delivers the global minimum by the pair x = 160 cm and y = 340 cm, however with value of about $0.01x\ 10^{-4}$.

The search algorithm through the data base delivers the result as shown in table III and IV. In the table, for each position, we propose four points available in the data base with nearest received power (minimal value of cost function).

Table III Result with cost function 1.

Pos.	Point 1 ($1x10^{-5}$)	Point 2 ($1x10^{-5}$)	Point 3 ($1x10^{-5}$)	Point 4 ($1x10^{-5}$)
1	100,340 (0)	130,430 (0.1316)	100, 400 (0.2566)	160,340 (0.2749)
2	160,340 (0.1127)	130,340 (0.1954)	130,520 (0.1971)	100,310 (0.2075)
3	190,340 (0.0814)	130,370 (0.2044)	130,310 (0.2152)	100,280 (0.2180)
4	250,340 (0)	220,430 (0.1955)	190,430 (0.2284)	220,40 (0.2446)
5	310,340 (0.1103)	10,190 (0.1401)	280,100 (0.1509)	310,430 (0.1546)

Table IV Result with cost function 2.

Pos.	Point 1	Point 2	Point 3	Point 4
1	100,340 (0)	100,430 (0.4994)	130,430 (0.6172)	100,310 (0.9159)
2	160,340 (0.3419)	190,340 (0.45)	130,340 (0.4819)	220,340 (0.7255)
3	190,340 (0.118)	220,340 (0.317)	130,310 (0.371)	130,340 (0.5807)
4	250,340 (0)	220,430 (0.5272)	220,340 (0.5534)	250,460 (0.5803)
5	40,160 (0.428)	310,460 (0.5463)	250,130 (0.5895)	280,100 (0.6449)

We see, positions 1 and 4 are chosen exactly at the positions x=100cm, y=340cm and x=250cm, y=340cm, respectively. These positions are available and we get exact received powers from calculation or measurement, so that we can refer the position searched to available positions in data base exactly. On the other hand, positions 2: x=150cm, y= 340cm, 3:x=200cm, y=340cm and 5:x=300cm, y=340cm are not given in data base. If we observe the four positions with minimal cost functions for each there three points in detail.

Fig. 7 and 8 show graphically the positions of point candidates by evaluating the cost function 1 and 2, respectively.

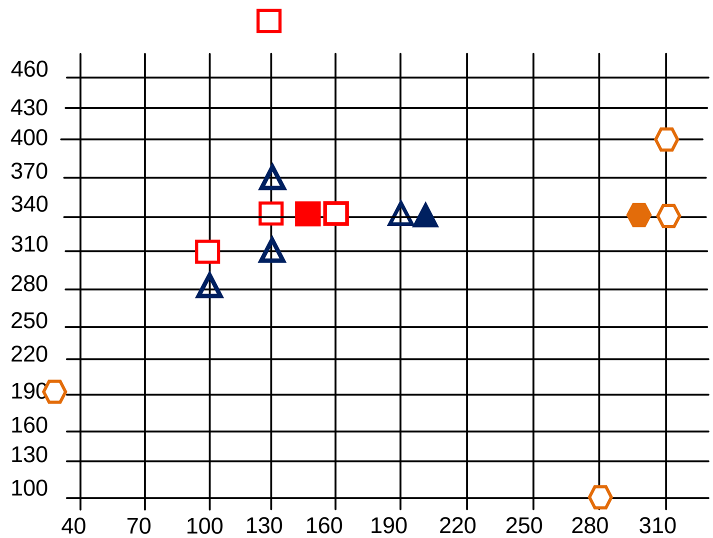

Fig. 7 Positions of candidates with cost function 1.

The filled symbols represent the actual positions of the tag. The empty symbols are the candidates of points obtained by calculating the cost functions having smallest values. We see the cost function 2 (Fig. 8) gives relative better results, because the candidates of point are close to each other.

For positions 2 and 3 we have rather good approximation positions, however for position 5, the position of the candidates are scattered away from the correct position.

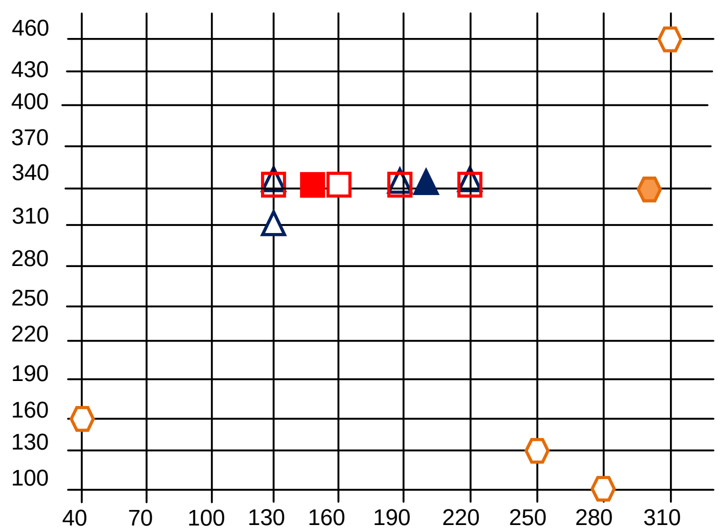

Fig. 8 Positions of candidates with cost function 2.

5 CONCLUSION

The polarization and diagram radiation of the antenna (reader and tag) play significant role in producing the pattern of received signal level. We show preliminary results according to effects of polarization and radiation diagram of antennas to field pattern, and consequently to positioning mechanism. Several questions are still open, how about the data base for other scenario, how accurate the data base must be, how many data must be stored. How about the cost function, which ones is the best. Last but not least, how we can find the correct position by given measured data, whether optimization method is necessary for this problem.

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