

RFID Indoor Localization System for Tag and Tag-free Target based on Interference

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Abstract— This paper proposes a passive UHF RFID indoor localization system for both tag and tag-free target based on interference. We take number of tags as landmarks and interpolate virtual tags using nature-neighbour interpolation. We monitor the interference by measuring the phase difference of reference tags. Two situations are considered: on the ground and in free-space. When tag or tag-free target is deployed, it likes a stone thrown in the water. The difficulty is find the projection point of tag or tag-free target. We use peak area and trough area to get the nearest reference points on the ground situation and use least square method to get the projection point in free space situation. The prototype was simply built comprising COTS RFID reader, Class 1 Gen 2 UHF tags. Measurement was carried out in an indoor environment, and the experimental result shows that the mean error is less than 6cm on the ground, and less than 30cm in free-space.

Keywords—UHF RFID, Localization, Passive tag, Tag-free, Landmark, Interference.

I. INTRODUCTION

The proliferation of Internet of Thing (IOT) and smart environment has attracted a great attention on indoor location system. Many services are based on the physical location of target, such as patient surveillance, storage management and quick seeking. In recent years, researchers introduced many technologies to address this issue, such as Wi-Fi [1], Bluetooth [2], ultra-sonic, ultra wideband (UWB) [3] etc. From the point of IOT, lower-cost, more-information and battery-less Terminals are more attractive. Passive ultra-high frequency (UHF) RFID is a suitable potential candidate in this application. RFID system is mainly consisted of reader and tag. The passive tag is battery-less and low-cost. When reader query the tag through radio wave, the tag harvest energy from the wave and modulate the backscatter. The RFID system could work from 860MHz to 960MHz in range of tens meters. These features make RFID a suitable method for indoor localization.

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In recent years, there have been great number of researches focus on RFID localization system. The methods could be mainly classified into the following three categories, and each category could be also classified into many subcategories.

1) Triangulation

This kind of method is widely used in radar system previously. It usual needs three channels to measure the distance or angle respectively. The distance measurement methods consist of Time of Arrival (TOA) [4], Phase of Arrival (POA) [5] and Received Signal Strength Indication (RSSI) [6] etc. The angle measurement methods consist of Angle of Arrival (AOA) [7], beam forming technique [8] etc.

2) Scene analysis

This kind of method need record the parameter of initial scene and then make predict to the later parameter after tag is introduced. Tag position could be localized through some special scene analysis methods, such as LANDMARC. [9] This system deploys several active reference tags which RSSI and coordinate is known. The position would be obtained through the weight distribution which is determined by the RSSI difference between tracking tag and reference tag. The VIRE system [10] introduces some virtual reference tags to deduce the cost and employs elimination algorithm to improve the accuracy. Differential based hologram localization method was introduced in article [11]. It divides the area into many subarea, and measures the phase of every subarea. If the target tag's phase is close to one given subarea value, it means the position of tag would be around at the subarea. Researchers also made a carpet using antenna and tags [12]. People wearing tags under shoes walk on the carpet. By measure the change of RSSI, researcher could get the people's position.

3) Tag-free

For tag-free situation, such as localization in market or detection of unauthorized access, researcher also prefer RFID system and have introduced several methods. Shop manager could get the customers' position and consuming behaviour without tag [13]. Some learning-based probabilistic approaches was introduced to explore tag-free RFID-based localization.[14] Researcher could even get the position of tag-free target though a wall, using tag array as sensors.[15]

There are also some other special research. Researchers [16] combined tag and camera, and use this battery-free camera to get position optically. Some filtering approaches were studied to minimize the effect of noise on the position estimation [17].

Above all, RFID localization has wide prospect in indoor localization. But little attention was paid to the RFID system which is suitable for both tag and tag-free target. This work is significant in consider of their important application. A RFID localization system for both tag and tag-free target would reduce system cost and increase system function. So our work focus on the localization method for both tag and tag-free target.

II. TECHNOLOGY AND IMPLEMENTATION

In this section, we firstly introduce the study of the interference of tags, and then conduct a series of experiences about localization of tag and tag-free target on the ground and in free space.

A. Our First Attempt

Passive RFID communication utilize the electromagnetic backscatter link. Tags harvest energy from the continuous wave (CW) signal supplied from antenna, and modulate the backscatter using on-off keying. So light-of-sight (LOS) is essential to the communication of RFID, and obstacle between antenna and tag may have an effect on the receiving signal, causing change of phase or amplitude. This feature is appropriate to localize the tag-free target [18, 19]. If the obstacle is tag, it is complicated. There are two aspects to be considered. On the one hand, tag antenna is considered as receiving end. The total receive signal is the vector sum of all waves, containing of reflection or scatter [20]. The simple tag structure limit its ability to distinguish the signals. So tag is susceptible to interference. The other aspect is that tag antenna could be considered as transmit end. Once the tag was activated, the backscatter signal would transmit to the free space without fixed direction. These two aspects could make the interference of tags a potential way to localize the tag and tag-free target.

We use COTS reader and tags to make empirical studies and observe the characteristics of interference. We deployed the antenna, tag-A, tag-B as shown in Figure 1, and we moved the tag-B perpendicularly between the antenna and tag-A. The sample point can be supposed as uniform distribution in 3m movement distance as the movement is a uniform rectilinear motion.



Figure 1. Attempt Experience

The phase result of tag-A is illustrated in Figure 2-(a). It suggests that the interference between tags is not limited to the LOS. It has periodic fluctuation due to the vector-sum signal. Then we replaced tag-B by a carton which is about the size of a deck of cards, and the phase measurement is shown in Figure 2-(b). It also has fluctuation and is similar to the phase change of moving tag-B. Figure 2-(c) shows the phase of tag-A without intentional introduced interference. We also measured the RSSI of the tag, but the change is so small that it is hard to detect. Shown from these empirical studies, the phase is sensitive to the interference of both tag and tag-free target. So our prototype environment take some reference tags as landmarks, and measure the phase difference of landmarks.

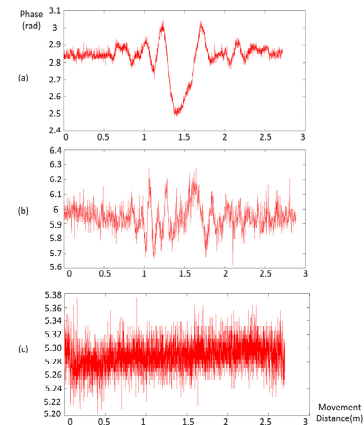


Figure 2. Phase change due to interference

B. Method and Approach

The prototype contains an Impinj R420 reader, a laird s9028pcr antenna, ALIEN AZ9662 tags and cables. The antenna is fixed on the housetop and the tags is placed on the ground as 11*11 array with 20cm space, as shown in Figure 3. Both antenna and tags have constant coordinate. For effective reading, tags are stick on PVC square tubes. In tag-free localization a bottle of water is used as target which diameter is 6cm and height is 20cm.

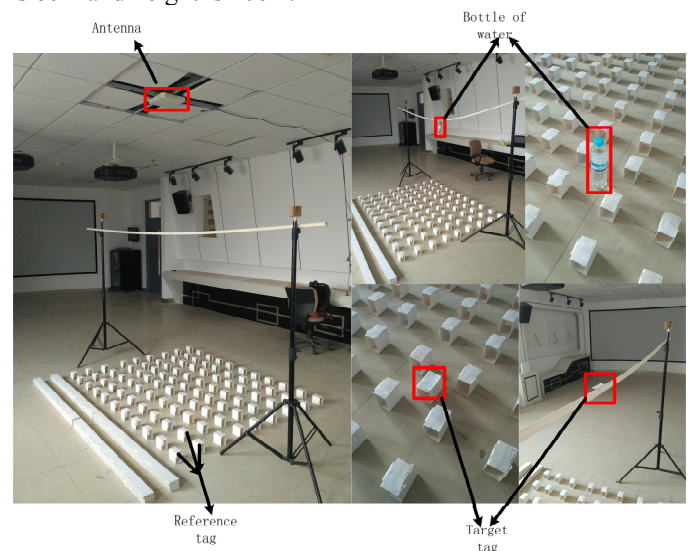


Figure 3. Prototype implement

Before introducing the target tags or items, we need to read all 121 reference tags and measure their phase respectively. These tags worked like sensors and the measurement are used as reference later. It is found that the distribution of phase error is normal distribution [20], so we take the mean of random variables as the measured value.

1) On the ground

In our study, we firstly take the ground as a special state because this situation is specific and would occur frequently. As our first experience shows, the target tag would interfere the neighbour reference tags. After deploying the target tag we measured the phase of reference tags and calculate the phase difference. To reduce the discretization error we implement natural neighbour interpolation and get some virtual reference tags. Figure 4-(a) shows the phase difference of reference tags and Figure 4-(b) is the top view. The '*' point is physical reference tags and other intersections are interpolating points. The x-axis and y-axis are the reference tags position coordinate and z-axis is the difference of phase. Obviously some of neighbour tag phases changed sharply, and other tags tend to be stable relatively.

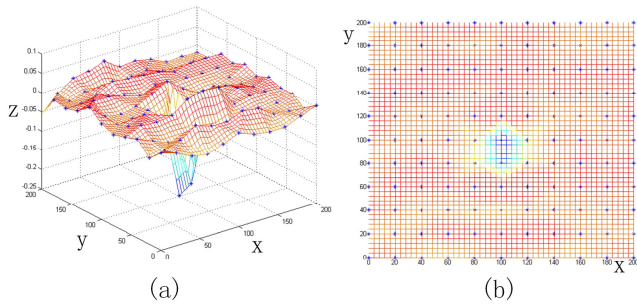


Figure 4. Phase difference of tag on the ground

The characteristic of interference determines that the phase difference is larger by decrease the distance to target tag. We made a bold and appropriate assumption that the actual position is in the centre of peak or trough area. We find the peak or trough area and make a minimal enclosing circle, where the centre of a circle is used as the coordinate of target tag. For the tag-free target, the phase difference is shown in Figure 5. It has the same localization method with the tag.

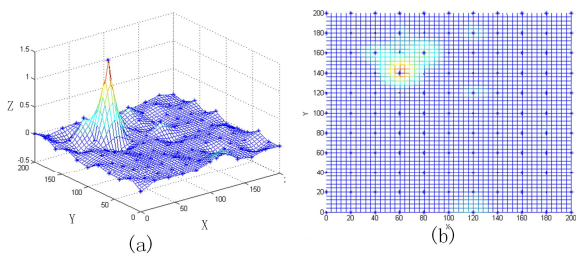


Figure 5. Phase difference of tag-free target

2) Free space

In this part, the localization in free space is more complicated than on the ground. Our study focus on two steps. One is to find the target tag projection point on the reference

tags plane. The projection point may be out of bounds when tag is deployed near bound and in enough height. The other is to get the precise distance between the target tag and antenna.

We put the target tag on the point of (70,130,150) and the phase difference is shown in Figure 6. The unit is centimetre. It looks like water ripples when a stone thrown into water. Our work is finding the centre point. Reference tags phase difference distribute as loops. It is relative to the different distances to the projection point. We could get several concentric arcs, and select the sufficiently long arcs as useful data. For each arcs we use least square method to fit the circle curves. The centres of circle is our projection point.

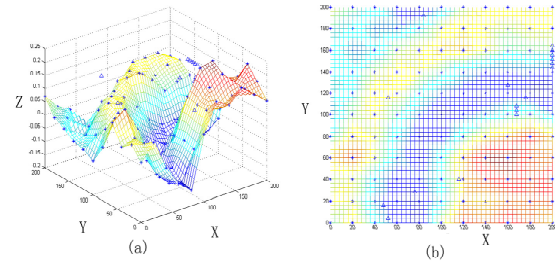


Figure 6. Phase difference of tag in free space

The second step is to measure the distance between antenna and target tag. Current RFID distance-measurement approaches mainly consist of time of arrival (TOA), received signal strength indication (RSSI), and phase of arrival (POA). The TOA-based method, learned from radar system, measures the time of wave propagation, and estimate the distance by multiplying the speed of light. For indoor location, the distance generally ranges from several meters to tens of meters. The propagation time is so small that is hard to be detected. The RSSI-based method is widely used in recent year, especially the logarithmic distance path loss model. This method need build prior theoretical or empirical model about distance and intensity attenuation of RSSI. It is hard to adapt different surroundings or directions. The POA-based method, accurately based on phase difference, use dual-frequency continuous wave to locate passive tags. The phase of received signal could be written as:

$$p = 2\pi \left(\frac{2d}{\lambda} - n \right) = 2\pi \left(\frac{f \cdot 2d}{C} - n \right) \quad (1)$$

Where C is speed of light, and n is the number of phase loops. We note that there is phase ambiguity problem, that is, the phase is periodic with 2π . To solve this problem, we use two carrier signals with different frequency: f_1 and f_2 . We could remove the n by make the difference of two phase as shown:

$$\Delta p = p_1 - p_2 = 2\pi \frac{\Delta f \cdot 2d}{C} \quad (2)$$

$$d = \frac{C}{4\pi} \cdot \frac{\Delta p}{\Delta f} \quad (3)$$

Inevitably error would be introduced in practical environment, so we provide some calibrations in our experiences. The error mainly comes from two aspects: One is mainly caused by reference tags. We have mentioned that the

reference tags have slight effect on target tag. Compared to other method, POA could eliminate the error by phase of difference. The other one is the initial error, which is mainly due to the different characters of cable and inter-circuit. So we measured the initial difference phase of two waves when tag is close to antenna. This difference is used as setting zero.

For tag-free target, we deployed a bottle of water in the experimental environment. The reference phase difference is shown in Figure 7, and the difference is similar to the surface of tag difference, while the localization has a little difference. For tag-free target, the distance between antenna and target cannot be measured by POA. Therefore we attempt to use two antennas to make two projection points, which is using to measure the tag-free target and improve the accuracy. Relative experiment is yet performing in lab.

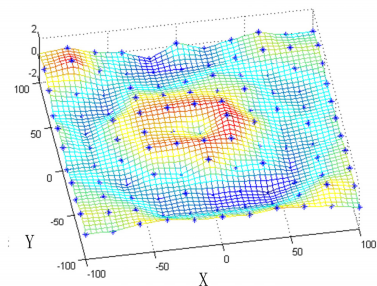


Figure 7. Phase difference of tag-free target in free space

C. Experimental result

On the ground, we deployed tag at coordinates: (130, 130), (70, 30), (160, 20) respectively and the result was shown in the Figure 8-(a). The unit is centimetre. We take a bottle of water as tag-free target, and deployed at coordinates: (70,150), (30, 70), (180, 80) and the position result was shown in the Figure 8-(b). The tag mean errors are less than 4cm and the tag-free position errors are less than 6cm. Figure 9 is the CDF of localization on the ground with 20 times measure.

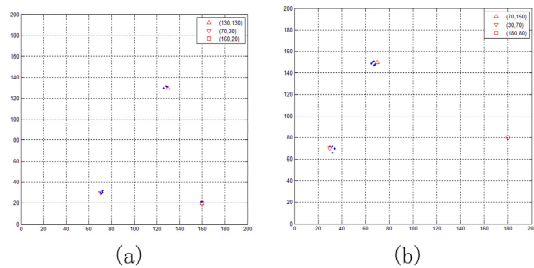


Figure 8. Position results on the ground

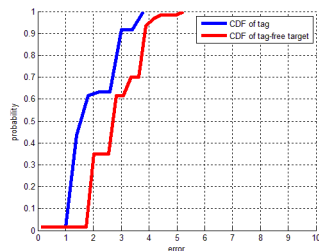


Figure 9. CDF result on the ground

Figure 10-(a) shows the result of tag localization in free space. The error is larger in compared with the ground. Figure 10-(b) is the CDF of tag localization in free space with 20 times measure. The reason is the limitation of POA method. The error is determined by the frequency difference, the larger difference, the smaller errors. Considering the frequency control in our country, our frequency band only ranges from 920.625MHz to 924.375MHz. The bandwidth is only 3.73MHz.

Tag-free localization is still experience in lab, we would add an antenna to realize the tag-free localization in free space, and could also improve the accuracy of tag localization.

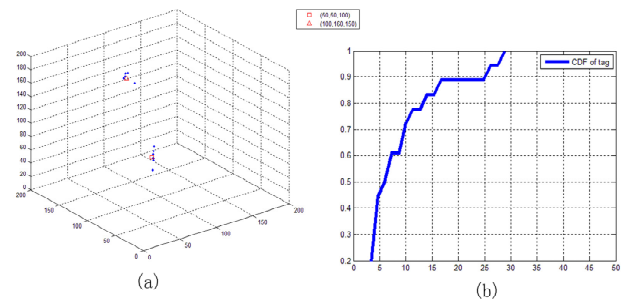


Figure 10. Position result and CDF of tag on free space

Table.1 shows the comparison of our work and other methods. Our work guarantees the accuracy but with lower cost. We combine the localization of tag and tag-free target, which would be a wider platform for RFID services.

TABLE 1. COMPARISON OF METHODS

	Methods		
	Our work	TOA[4]	VIRE[10]
Tag localization Accuracy(cm)	Ground:6cm Free space:30	4.68	29
Cost	low	high	high
Tag-free localization	Yes	None	None

III.CONCLUSIONS

A novel RFID localization method was introduced in this paper. We use the interference of tags to realize the localization of tag and tag-free target. Compared to the traditional method, our system need little cost. The system used array of reference tags instead of multi readers to capture the position information. The position result errors mean error is less than 6cm on the ground, and is less than 30cm in free-space.

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