# Reading Activity Recognition in Smart RF-Library

Yegang DU, Yuto LIM and Yasuo TAN
*School of Information Science, Japan Advanced Institute of Science and Technology
1-1 Asahidai, Nomi, Ishikawa, Japan
{duyegang, ylim, ytan}@jaist.ac.jp

***Abstract*—In the library, recognizing the behaviors of readers can better excavate the reading habit of the readers and bring convenience to the book management. We present the design and implementation of a reading activity recognition approach utilizing passive RFID tags. By collecting and analyzing phase value distribution feature, our approach can recognize which book has been picked up. We give a detailed analysis of factors that can affect phase value in theory and combine these factors with relevant activities. And then we infer the activities in real time through monitoring the phase of tags. Besides, we implement our approach with off-the-shelf RFID equipment.**

***Index Terms*—RFID, Activity Recognition, Smart Library, Wireless Sensing, Internet of Things.**

## I. Introduction

Nowadays, more and more smart personalized recommendation are applied to improve the consumer services. Most of them only use the knowledge from online interaction which is obviously not enough. Actually, more offline activities such as reading activity in the library can also be utilized to promote the intelligent services, especially with the development of large scale RFID system [1]. Our long-term goal is to develop a context-aware system that can automatically recognizes reader activities in real time and provides personalized services to the reader according to the specific activity in smart library. In this paper, we focus on reading activity recognition based on passive RFID technology. With our approach, which book has been picked up and the location of reader can be sensed.

There are three main advantages of our approach relative to other waveform-based activity recognition [2]. Firstly, only when the distance between the reader and the book shelf is short enough, the phase waveform can be identifiable while the reader walks before a book. According to verification experiment, our approach still works even when the distance is greater than 80cm. Secondly, the computation complexity of our approach is obviously much lower, because our approach does not have to generate particular waveform for each activity. Last but not the least, people may pick up a book in different ways, and therefore causes totally different phase waveform.

## II. Preliminaries

This section will give a detailed analysis of factors that can affect phase value. We believe that the phase of a tag is determined by three aspects: distance, angle, and multi-path effect.

### A. RF Phase Values

In a basic RFID system, the reader transmits continuous-wave signals to the tags, and then receive backscattered signals from the tags. The phase value of RF signals describes the offset between the transmitted and received signals, which depends on the round-trip ($2d$) and hardware-specific factors [3]. $d$ is the distance between antenna and tag. For a standard phase-distance model, the hardware-specific factors include three parts: $\theta_T$, $\theta_R$ and $\theta_{TAG}$, which caused by the reader's transmission circuit, the reader's receiver circuit and the tag's reflection characteristic. Besides, the RF phase is a periodic function ranging between 0 and $2\pi$. Thus, the phase value $\theta$ of a tag measured by the reader can be expressed as:

$$\theta = mod(2\pi\frac{2d}{\lambda} + \theta_T + \theta_R + \theta_{TAG}, 2\pi) \quad (1)$$

where $\lambda$ is the signal wavelength [4]. The phase value is a common attribute that is supported by most COTS RFID readers, e.g., ImpinJ R420 [5]. Note that the hardware-specific factors are constant since the devices are produced. Phase measurement contains random errors in real world situation, and different tags have different levels of random errors following a Gaussian distribution with a standard deviation of 0.1 radians. As denoted in Eq.1, phase is linear to the distance between antenna and tag ignoring the random error.

For example, ImpinJ R420 can be set to work at 920∼926 MHz with 16 channels. Thus, the $\lambda$ is about $320mm$ and the $\theta$ will repeat if the difference of distance is larger than $160mm$. Especially, when the $\theta$ is close to 0 and keep reducing, it will jump from 0 to $2\pi$, and vice versa. This is called "phase jump".

### B. Rotation of Tags

The phase of a tag is affected by the relative orientation to the reader antenna. This observation is mentioned in Wei's research published in 2016 [6]. To reinvestigate this phenomenon, we carry out an experiment as Fig.1.

As depicted in Fig.1, we place a slim tag 1 m in front of a reader antenna. The center of antenna and tag is in a horizontal line to make sure that the distance between antenna and tag is invariable. Then, rotate the tag along each axis. Moreover, the tag is placed facing the antenna with both front and side respectively to investigate if the posture of tag itself will influence the phase or not.

The result is shown by Fig.2. In Fig.2(a), there is only one line. Because, when the tag rotating along Z-axis, the posture

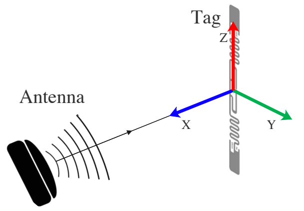
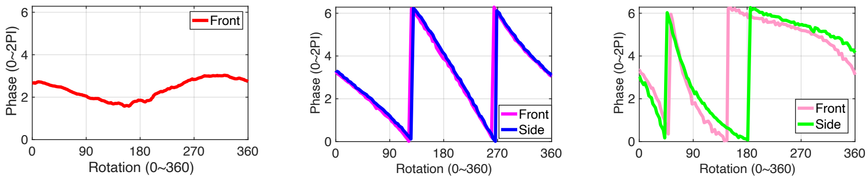



Fig. 1. Measuring the phase of a tag rotating along each axis.




(a) Rotate the tag along Z-axis (b) Rotate the tag along X-axis (c) Rotate the tag along Y-axis

Fig. 2. Measured phase of a tag rotating along three axes respectively.

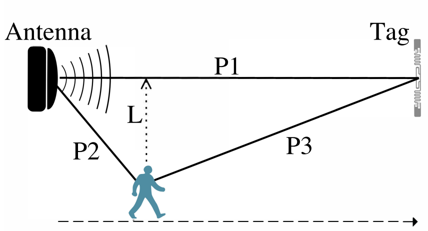



Fig. 3. Measuring the phase under multi-path effect.

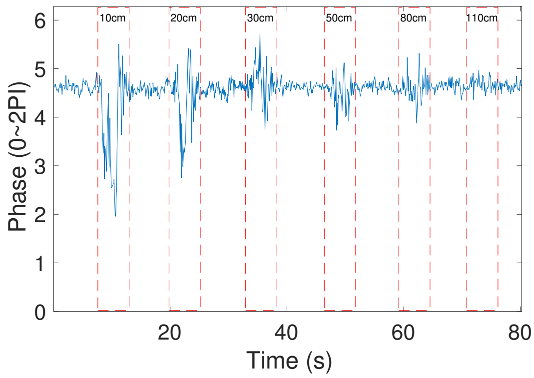



Fig. 4. The phase changes while $L$ is set from 10cm to 110cm. The phase in red frame is affected by multi-path effect.

of tag does not matter. We can see that the phase does not change much while rotating along Z-axis. However, it shifts periodically when it rotates along X-axis and Y-axis as it is shown in Fig.2(b) and Fig.2(c). The phase changes linearly with rotation along X-axis and nonlinearly with rotation along Y-axis. And the phase will jump twice in one period. Wei [6] explains this phenomenon with the polarity of RFID antennas. It means that the phase will change $\pi$ when rotating around both X-axis and Y-axis by 90°. Besides, we can find that no matter the tag is facing the antenna with front or side, the phase changes in a same pattern.

### *C. Multi-path Effect*

RFID signal is a kind of radio wave with specific frequency. So it has to suffer the multi-path effect as other radio waves do [7]. The wireless signal is radiated to all directions rather than a line. While some signal goes directly to the destination, some other signal is reflected by surroundings then goes to the destination. Thus, different paths are generated. Multi-path effect is caused by the difference of distance of these paths. Multi-path effect will influence the phase according to Eq.1.

To better understand the multi-path effect, we monitor the phase under multi-path effect in real world situation as described in Fig.3. A tag is placed 2m in front of antenna. $P1$ is a line-of-sigh(LoS) path. A man walks along a straight line parallel with $P1$ and the gap between $P1$ and the man is $L$. Thus the signal reflected by the man will generate a new path $P2$-$P3$. The man repeats walking along the line changing $L$ from 10cm to 110cm. The phase measured by the reader is shown by Fig.4.

From Fig.4, we can see that the rangeability of phase becomes smaller and smaller as the growth of $L$. And when $L$ reaches to 110cm, it is hard to distinguish between multi-path effect and random error.

**Inspiration:** Previously, we analyze three aspects that can bring about changes to phase value. Specifically, activities in library imply these aspects more or less. This inspires us to infer the activities by monitoring the transformation of the phase value. Although there are some applications based on RFID phase applied to the area of object use detection [8] [9], gesture recognition [2], indoor localization [3], etc., this paper is the first to do activity recognition in the library according to the intensity of variation of phase. The detail of our system is expounded in the next section.

## III. System Design

In this section, we present the details of our approach to detect the activities based on RFID in the library. Our approach utilizes the RFID reader antenna placed on the top of book shelf to monitor the phase value of tags attached on books. We give a analysis of the relation between activity and phase transformation firstly. Then, a method based on phase value distribution is proposed to infer the activity as shown in Fig.5.

### *A. Activity Definition*

Generally speaking, a reader's behavior in the library follows a common process. Firstly, the reader walks to the area where there are books he has interest in. Secondly, the reader

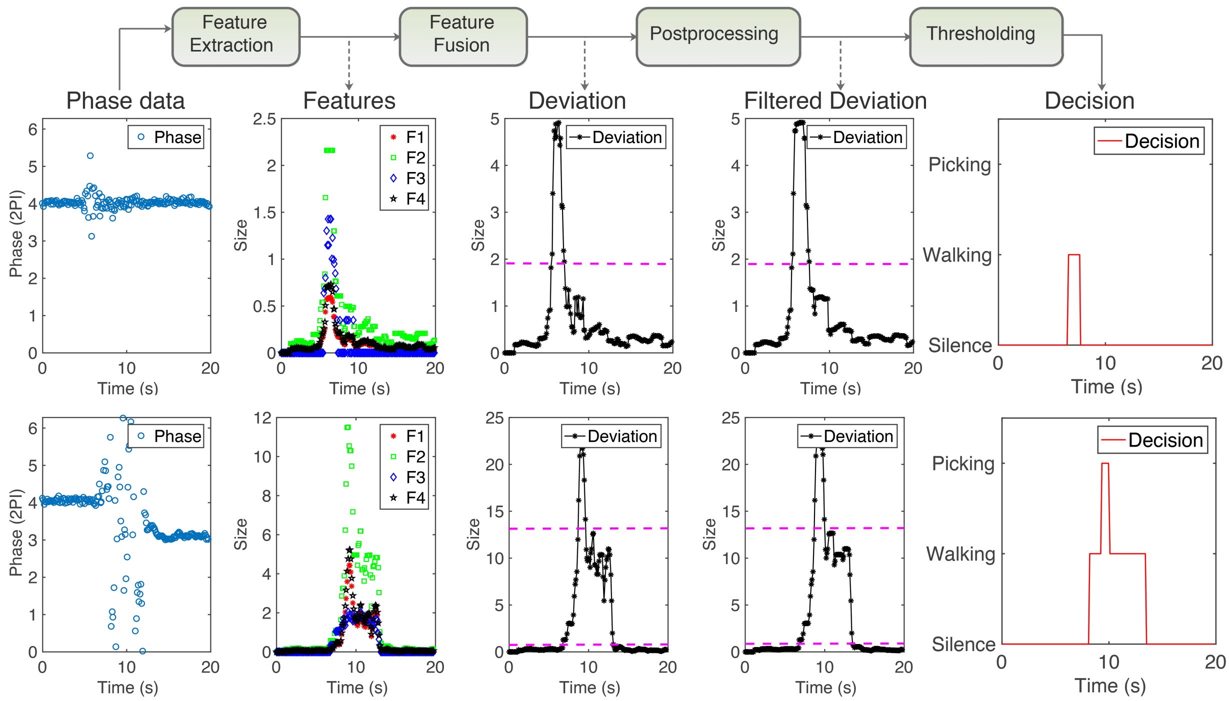



Fig. 5. The architecture of activity recognition approach. F1, F2, F3 and F4 in the second picture represent four features respectively. The upper line is an example of walking before a book and the under line is an example of picking up a book.

will pick up books one by one and read for a little while to find out the ones that he prefers to read through. Then, he will take the books to the reading area. After reading, he replaces the books to where they were. This process actually contains four activities: walking before a book, picking up books, taking books away and putting books back. Because the RFID antenna has a limited examination area, it is easy to detect whether one book is taken away or put back just through the tag's visibility. Thus, the challenge is how to distinguish the first two activities with each other. Of cause, there is also a static status means no one comes into the examination area.

According to the analysis in Section II, it is obvious that walking before a book only causes the multi-path effect, in the meanwhile, picking up a book will change both the angle of tag and the distance between tag and antenna.

### *B. Data Collection*

We implement our approach in one book shelf on which there are 50 books in total as depicted in Fig.6. And we collect RFID data using a ImpinJ R420 reader with only one antenna, setting the reader in max-through power and dual target search mode [10]. The slim tags are attached on the back of each book. The reader keeps querying the state of every tag within the examination area. In our situation, the mean sampling rate for each tag is about 12 times per second.

where $p$ is the phase value. The regularization first generates the mean value of the true phase value and the fake phase

Fig. 6. The white antenna is placed at a 45° angle to the ground to ensure it can cover as much region as possible, because of its fan-shaped radiation regions.

value. Then, it zooms in the value from $0.5\pi \sim 1.5\pi$ to $0 \sim 2\pi$. Note that the regularization will not affect the tendency of the phase, even though it changes all of the phase value. In addition, it will double the dispersion degree which is good for our approach.

### *C. Phase Dispersion of Activity*

Other than the phase waveform-based activity recognition approach [2], we recognize the activity based on the phase dispersion within a sliding window. We first extract the features to describe the phase dispersion, then we use weighted summation method to fuse the features into a deviation index. After postprocessing, we can finally generate the recognition decision.

The traditional indexes to weigh the dispersion include: standard deviation, range, entropy, coefficient of variation, etc. In this paper, we mainly use the first three features to describe the phase dispersion. Besides, we believe that the arithmetical average deviation of phase values in a sliding window also can be used as a feature. For a phase data set $(X)$ in a sliding window, the intensity of phase variation can be described by the following indexes: standard deviation $\sigma(X)$, range $R(X)$, entropy $H(X)$ and average deviation $\delta(X)$.

$$M(X) = exp(c_1\sigma(X) + c_2R(X) + c_3H(X) + c_4\delta(X)) \quad (2)$$

Finally, the comprehensive deviation $M$ can be calculated by Eq. (2), where $c_j$ is the weight of features.

### D. Thresholding

In this paper, we first need to detect if there is an activity, then we further recognize if the activity is picking up a book or not. If it is not picking up a book, it must be walking before a book. To ensure the system can achieve good instantaneity, we chose thresholding rather than some complex machine learning techniques.

## IV. Experiment and Evaluation

To evaluate the proposed approach, we carry out some experiments. The performance $P$ is judged by recognition precision, as shown below:

$$P = \sum_{i=1}^{N} \frac{A_t}{m} \quad (3)$$

where $N$ is the quantity of books which is 50 in this paper, $A_t$ is the right recognition. $m$ is the frequency of test activities. Note that, if there is no one walking before the book shelf, the system will keep silence. Within 1 hours, there is no false positive. Thus, our approach works very well on detecting readers.

In the first part, we ask five volunteers who differ from each other in both height and weight to walk past the book shelf from left to right and the opposite direction again 25 times respectively. And then calculate the precision, as shown in Table I.

TABLE I
Performance of detecting walking past.

| Volunteers | P1 | P2 | P3 | P4 | P5 |
|---|---|---|---|---|---|
| Precision | 97.28% | 95.92% | 96.76% | 96.88% | 95.84% |

In the other part, we ask a volunteer to walk to the book shelf and randomly pick up a book and put it back then walk away. This is repeated 50 times. The two results in Table II reflect the partial and the overall precision. In the former one, we only consider the books that have been picked up. And in the latter one, we take all the books in to calculation.

TABLE II
Performance of detecting picking up.

| Result | Partial | Overall |
|---|---|---|
| Precision | 96% | 92.2% |

The overall precision is 92.2% which is lower than the first part of experiment. It is because when a book is picked up, it will cause influence to the neighbor books. In the future research, we will try to avoid this error.

## V. Conclusion

In this paper, we analyse the feasibility for detecting activities in the library using RFID phase in theory. Then we find that the variation of RFID phase can reflect the interaction between the reader and the books. Afterwardswe process the phase signal of tagged books and distinguish different activities with thresholds. Finally, we implement our approach to evaluate the performance and the overall precision can reaches to 92.2%.

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