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Deep Learning-based UHF RFID Tag Collision Detection Method

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Abstract

This paper presents a novel deep learning-based radio frequency identification (RFID) tag collision detection method for ultra-high frequency (UHF) RFID. UHF RFID technology provides longer communication range compared to NFC, barcode, and QR code technology. However, due to the longer range, multiple tags in wide range may reply simultaneously such that a reader receives superposed signal of multiple tags. Multiple tag signals interfere with each other such that reader's tag reading speed is decreased. In order to detect these tag collisions, previous studies utilized analytical methods rather than theoretical ones. Hence, a deep learning-based solution can improve the detection performance. For deep learning, training datasets are generated from mathematical equations, which are specified by the standard, with various delay times, amplitude differences, phase differences and noise level among tag signals. Arbitrary delay time, phase difference, and amplitude difference are used in every run of simulation. Simulation results show that the detection performance using the proposed method is about 5 dB better than that of existing method.

Keywords: *Deep learning, UHF, RFID, Tag*

1. Introduction

Due to the Covid-19 pandemic, online services are becoming more widespread. For online services in logistics, advancement of logistics automation is necessary such as robot-based platform and long distance tag identification. For example, for robot-based platform, amazon expands robot use in warehouse and Boston Dynamics develops logistics handling robots [1-2]. And, barcode (including QR code), near-field communication (NFC), or ultra-high frequency (UHF) radio-frequency identification (RFID) may be used to identify product information. Barcode, including QR code, technology utilizes optical method and UHF RFID and NFC utilize wireless method. Compared to UHF RFID, a barcode is cheap and can be printed on a paper. However, barcode is operated only in line-of-sight. Hence, since a barcode must be aligned to reader, the automation is somehow difficult. Like UHF RFID, NFC uses wireless technology. However, since tag identification range is less than 1 cm, which is shorter than that of barcode, the automation may be difficult.

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UHF RFID can be operated in non-line-of-sight environments. And, tag identification distance of RFID is much longer than that of NFC. In addition, UHF RFID tag price is dropping rapidly due to the development of semiconductor technology. Recently, these advantages of UHF RFID technology gains more attention as the IoT technology [3-5]. In [3], it has been shown that UHF RFID technology is used to monitor student attendance automatically and so time is saved. In [4], it has been presented that personal healthcare system is becoming more advanced by utilizing advantages of UHF RFID technology such as low-cost, wireless connection, wireless energy transfer. And, in [5], it has been shown that UHF RFID technology enables automatic and multiple toll charge collection. However, due to the longer tag identification distance, multiple tags in wide range may reply simultaneously such that a reader receives a superposed signal of multiple tags. This results in a tag collision. Multiple tag signals interfere with each other such that reader's tag reading speed is decreased. The RFID reader must detect and resolve tag collision [6-7]. Various methods for detecting tag collision have been studied in previous works [8-9]. In [8], it has been shown that collided tag signals have multiple dominant signal levels. In [9], it has been shown that tag collision can be detected utilizing the periodic characteristics of tag signal. It is worth noting that previous studies utilized analytical methods rather than theoretical ones. Hence, a deep learning-based solution can improve the detection performance.

This paper presents a deep learning-based UHF RFID tag collision detection method. Section 2 describes tag collision in UHF RFID inventory policy. The deep learning-based method is described in Section 3. Section 4 presents simulation results. Finally, conclusions are presented in Section 5.

2. UHF RFID Tag Collision

Figure 1 shows UHF RFID tag inventory procedure and tag collision [10].

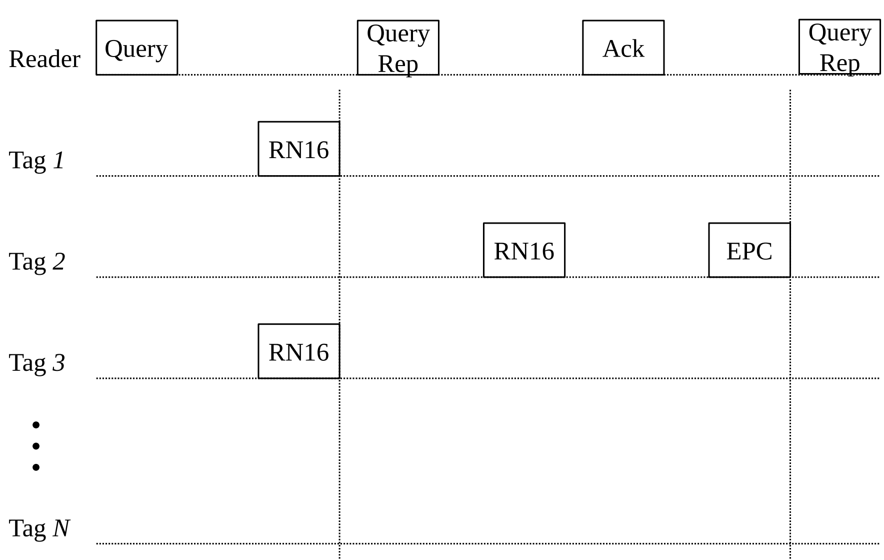


Figure 1. Tag inventory and collision

UHF RFID tag inventory is based on the slotted additive links online Hawaii area (ALOHA) protocol [11]. If tags receive 'Query' command, tags reply '16-bit random or pseudo-random number (RN16)' after the tags select the time slot randomly [10]. As shown in Figure 1, if more than two tags reply simultaneously at the same time slot, it causes the tag collision. It is worth noting that there is no carrier frequency offset among tag signals and reader because UHF RFID tags reflect (backscatter) the reader's carrier signal. So, the simultaneous replied tag signals $r_T(t)$ is written as

$$r_T(t) = \sum_{k=1}^{n} A_k s_k(t - \tau_k) e^{j\theta_k} + n(t) \tag{1}$$

where n denotes the number of simultaneous replied tags, k denotes the index of k-th tag signal and $s_k(t)$ denotes the k-th tag signal. A_k and θ_k are amplitude and phase offset of k-th tag signal, respectively. And, $n(t)$ denotes additive white Gaussian noise (AWGN). Equation (1) shows that the simultaneous replied tag signals have different delay time, phase, and amplitude.

3. Tag Collision Signal Dataset and Learning

Figure 2 shows a square wave of a tag signal. Tag signal has at least 1 period of square wave in *1*-bit.

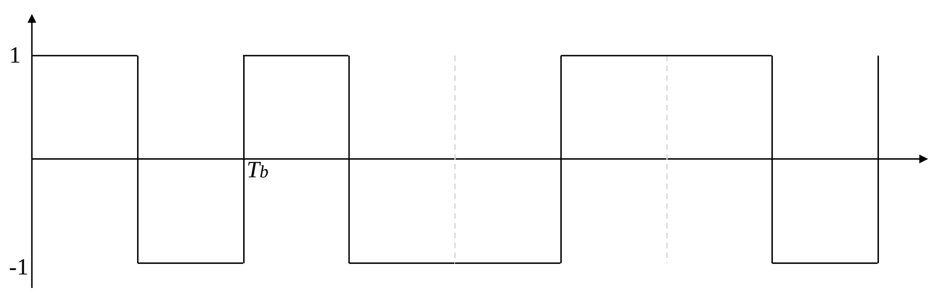


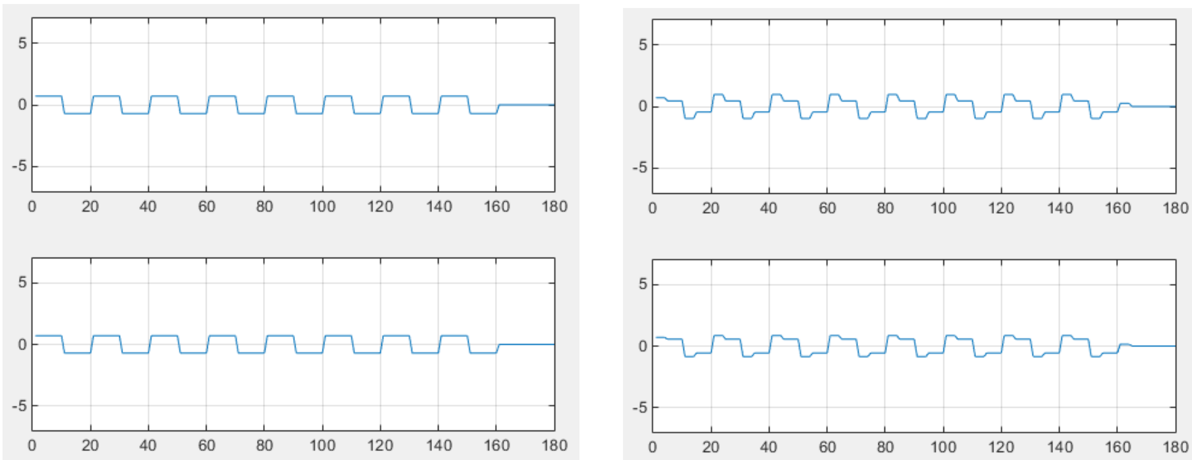
Figure 2. Square waves of a tag signal

For tag collision training, two tag signals are used. Since tag signal is specified by the standard, training dataset can be generated from mathematical equations [10]. In addition, training dataset must be generated by considering Equation (1). Table 1 shows the parameters for training dataset generation. Consequently, 220,000 cases are used for learning.

Table 1. Parameters for training dataset generation

Parameter	Specification
Time delays between two tag signals	11 points in 0 ~ $0.5T_b$
Phase differences between two tag signals	5 points in 0 ~ $\pi/2$
E_b/N_0	4 points in 5 ~ 20 dB
Noise signals	1,000 signals for each E_b/N_0

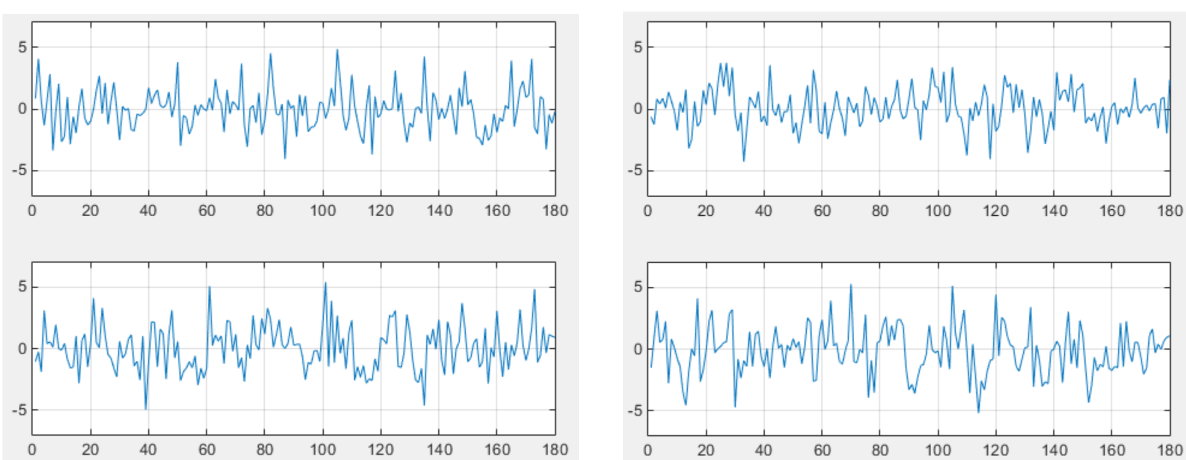
Figure 3 shows no noise signals in training dataset. We can find that tag collision in (b) can be determined by using the method proposed in [9]. It means that since the number of periodic edge in *1*-bit is more than 1, it is determined that tag collision has occurred. Even edges may be generated by noise, those may not be periodic, it cannot be determined as tag collision.



(a) (b)

Figure 3. No noise signals (a) single tag signals (upper: real, lower: imag) and (b) two tag signals (upper: real, lower: imag) : delay of 0.2T_b, phase difference of $\pi/12$, and amplitude difference of 30%

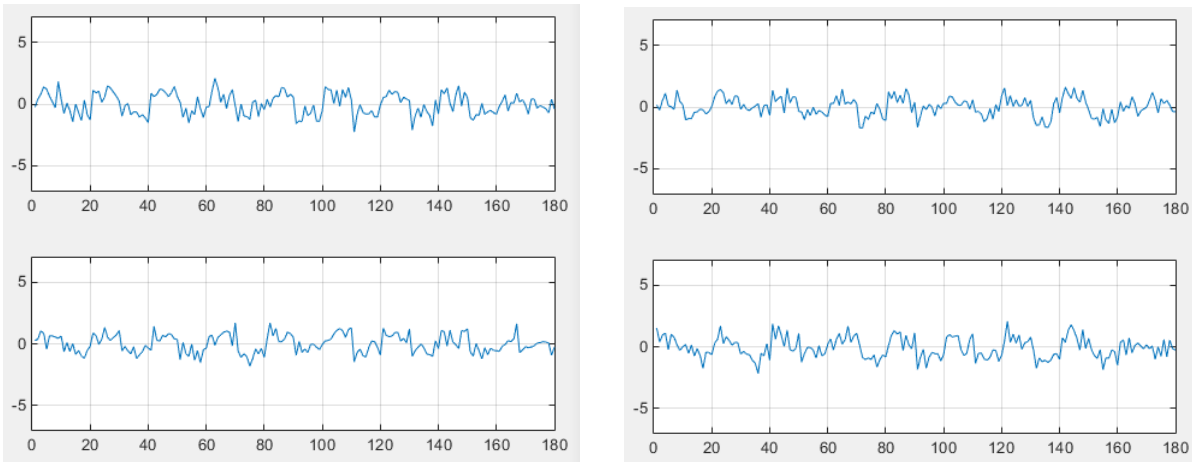
Figure 4 shows noisy signals of E_b/N_0 of 5 dB in training dataset. We find that it is hard to find difference between (a) and (b).



(a) (b)

Figure 4. Noisy signals of E_b/N_0 of 5 dB (a) single tag signals (upper: real, lower: imag) and (b) two tag signals (upper: real, lower: imag) : delay of 0.2T_b, phase difference of $\pi/12$, and amplitude difference of 30%

Figure 5 shows noisy signals of E_b/N_0 of 15 dB in training dataset. We find that it is not easy to distinguish between (a) and (b). It is worth noting that signals in Figure 3 and even signals in Figure 4, 5 are used for the learning.



(a) (b)

Figure 5. Noisy signals of E_b/N_0 of 15 dB (a) single tag signals (upper: real, lower: imag) and (b) two tag signals (upper: real, lower: imag) : delay of $0.2T_b$, phase difference of $\pi/12$, and amplitude difference of 30%

Designed neural network structure for learning is presented in Table 2.

Table 2. Neural network structure parameters

Parameter	Specification
No. of node in input layer	64
No. of hidden layer	2
No. of node in first hidden layer	128
No. of node in second hidden layer	10
Data set partitioning	train_test_split in scikit-learn library
Optimization technique	Adaptive moment estimation
Loss function	Sparse categorical crossentropy

4. Simulation and Results

Since the distance between tag and reader can be represented by E_b/N_0, detection performance of various E_b/N_0 values is used for the performance evaluation. Figure 6 shows the simulated detection performance of the proposed method.

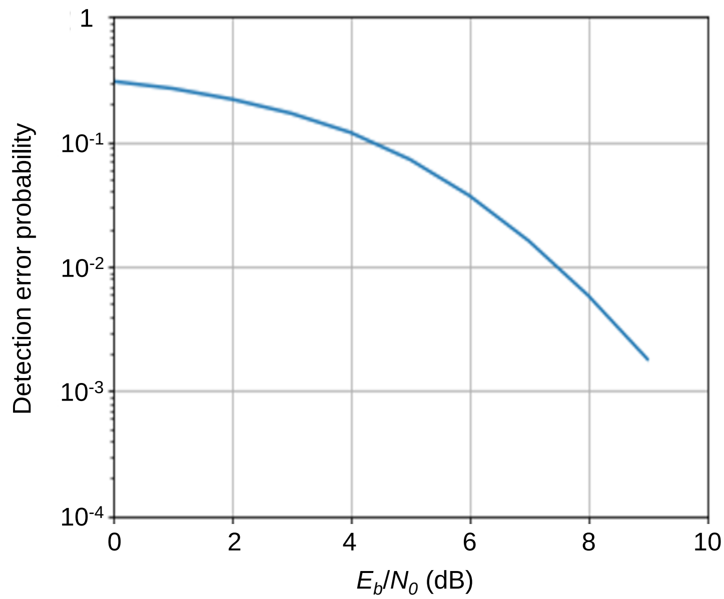


Figure 6. Simulated detection performance

During the simulation, 10,000 runs are used for each E_b/N_0 value. It is worth noting that arbitrary delay time, phase difference, and amplitude difference are used in every run. It shows that the detection performance using the proposed method is about 5 dB better than that of existing method [9]. Table 3 compares the characteristics of tag collision detection methods.

Table 3. Characteristics comparison of tag collision detection methods

Characteristics	This work	[9]
Detection error probability of 10^{-3}	9.5 dB	14.5 dB
Throughput	high	low
Complexity	high	low
Detection speed	slow	fast

5. Conclusions

In this paper, UHF RFID tag collision detection method utilizing deep learning has been presented. Deep learning-based solution is more suitable than existing methods because the existing methods utilized analytical methods rather than theoretical ones. For deep learning, training dataset are generated from mathematical equations, which is specified by the standard, and generated with various time delay, phase difference, and amplitude difference. Tag collision occurs more frequently as tag identification distance is longer. The distance between tag and reader can be represented by E_b/N_0. Hence, in order to evaluate performance of proposed method, detection performance of various E_b/N_0 values has been used. Simulation results have shown that the detection performance using the proposed method is about 5 dB better than that of existing method. It means that tag identification distance can be increased as much as two times compared to existing method.

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