Developing an intelligent library gate to detect unauthorized borrowing and to minimize electrical power consumption

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Abstract

Recently, many libraries have introduced a UHF-band RFID tag system because of its convenience. However, the UHF-band RFID reader has wide coverage area and this can reduce the management efficiency by unintentionally reading unnecessary tags. In this paper, we propose an intelligent library gate by using machine learning algorithm. The intelligent gate takes into account relative angle and distance between RFID tags and the reader and controls the intensity of the radio wave emitted from the reader by using machine learning algorithm. This enables the reader to maintain detection accuracy and minimize electrical power consumption. In order to validate the effectiveness of the gate, SVM is used to predict RSSI. The result of the prediction shows RMSE as 7.67 and R-squared as 0.77. Electrical power consumption is reduced to 59 % compared to a case when the radio wave is emitted at maximum intensity. The result shows that the intelligent gate which maintains detection accuracy and minimize electrical power consumption can be developed by selecting minimum necessary radio wave intensity predicted in the experiment.

Key words
RSSI, regression model, ultra-high frequency RFID, intelligent gate, SVM

1. Introduction

Large scale libraries, such as those in universities, have introduced RFID system. In this system, each material has a barcode or a RFID tag and a special reader is used to read the material ID code recorded in the barcode or the tag. In this way, a user can smoothly borrow and return materials (Singh and Mahajan, 2014, Roy and Kumar, 2017). An unauthorized borrowing is detected by a special gate at the library exit. Existing systems mainly use barcodes and HF-band RFID tags for material management. Recently, however, the number of libraries using UHF-band RFID is increasing because the system offers convenience (Cheng et al., 2017). Compared to barcodes and HF-band RFID tags, UHF-band RFID tags offer long range readability (Ching, et al., 2009). While the existing management system using barcodes or HF-band RFID tags requires each material to be processed separately, UHF-band tags allow multiple materials to be processed simultaneously (Dhanalakshmi and Mamatha, 2009). Also, the UHF-band RFID tag system makes it easy to find a material in the library (Dhanalakshmi and Mamatha, 2009). Existing studies, however, point out following issues when UHF-band RFID tags are used for library management:

- By using a special reader/writer, an unauthorized person can read and alter ID code stored in the RFID tag. (Avoine et al, 2005; Molnar and Wagner, 2004).
- By wrapping a book with substance which shields radio wave, such as aluminum foil, ID codes become unable to be read by the reader (Ching et al., 2009).
- Unnecessary alarm may be activated by reading an RFID tag of a book which a user is carrying to a reading corner but temporarily walking near the gate (Goto, 2012).

All these three issues are worth solving, but in this paper, we focus on the third one.

We propose an intelligent gate by using machine learning algorithm in order to address this issue. When UHF-band RFID tags receive a radio wave emitted from a UHF-band RFID reader, they reflect the radio wave along with ID code to the reader. The reader receives the wave and detects the ID. The intensity of the wave received by the reader is called received signal strength indicator, or RSSI. RSSI is inversely proportional to the square of the distance between the tag and the reader. Read range is defined by the intensity of the wave emitted from the reader and the size of the RFID tag. Detection accuracy depends on relative angle and distance between the RFID tag and the reader. A stronger radio intensity from UHF-band RFID reader allows wider read range and higher detection accuracy. Hence, the existing systems in the libraries set a stronger intensity for the reader at the gate to emit in order to improve detection accuracy. However, this wave characteristics and the settings lead to the issue we are addressing in this study. In this study we take into account relative angle and distance between the RFID tag and the reader and control the intensity of the wave emitted from the reader by using machine learning algorithm in order to maintain detection accuracy and minimize wave intensity.

There are two advantages for this intelligent gate. First, the number of unnecessary alarm to a user not intending to leave the library will decrease. Second, the electrical power consumption can be reduced since a RFID tag can be read by minimum wave intensity.

In order to validate the effectiveness of the intelligent gate, RSSI is predicted by using SVM, a machine learning algorithm (Cortes and Vapnik, 2009). The result of the prediction by SVM shows RMSE = 7.67 and R-squared = 0.77. Electrical power consumption is reduced to 59 % compared to a case when the maximum radio wave is emitted. The result shows that the intelligent gate which maintains detection accuracy and minimizes electrical power consumption can be developed by selecting the minimum radio wave intensity predicted in this paper.

Chapter 2 describes the configuration of the intelligent gate. Chapter 3 explains the experiments and the results to validate the effectiveness of the gate. Chapter 4 concludes the paper and outlines the future direction of the study.

2. Intelligent gate

In this material study, we propose an intelligent gate by using machine learning algorithm. Figure 1 illustrates a configuration of the intelligent gate. First, we obtain the relative angle and the distance between a material and a RFID reader. Read range is defined by the intensity of the wave emitted from the reader and the size of a RFID tag. Detection accuracy depends on relative angle and distance between the RFID tag and the reader. Hence, we control the intensity of the wave emitted from the reader in order to maintain detection accuracy and minimize wave intensity.

Second, the obtained data are input into a regression model. To maintain detection accuracy, RSSI, or the intensity of the wave reflected from a RFID tag, should be predicted. When the reader cannot read a RFID tag from a material, RSSI is –100. An optimum wave intensity, therefore, is one which realizes RSSI to be larger than –100 and uses minimum electrical power consumption. In the experiment, we use several wave intensities to find a minimum wave intensity which the regression model predicts the value of RSSI to be larger than –100. We use Support Vector Machine to develop the regression model for RSSI prediction. The wave intensity with RSSI value predicted as larger than –100 and minimum wave intensity is selected. The RFID reader emit the wave with the selected intensity and read the RFID tag.

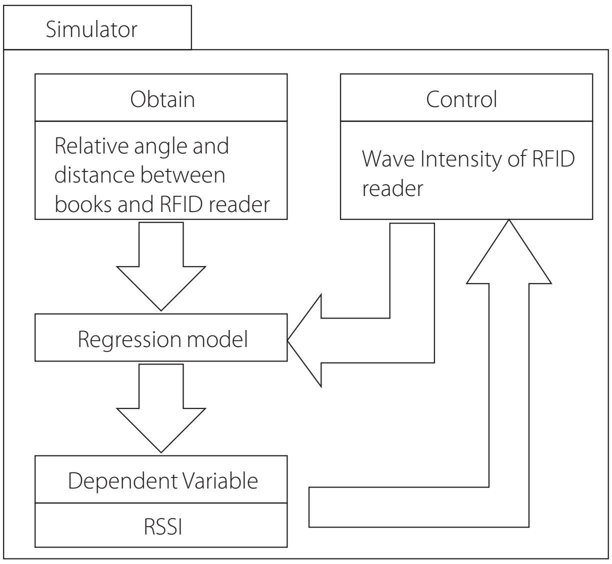

Figure 1: RSSI prediction using regression model

3. Validation of the intelligent gate effectiveness

3.1 Experiment

In this material experiment, we validate the prediction accuracy of the regression model to show the effectiveness of the material study. Figure 2 illustrates the experiment environment. RFID tags are attached to the center of back cover of a material. Dog Bone tags from SMARTRAC are used in the experiment. The size of each tag is 27.0mm × 97.0 m. The operating frequency range is between 860 MHz and 960 MHz. The maximum operating distance is 6.5 m. As a RFID reader, we use DOTR-910J from Tohoku System Support. A circularly polarized antenna is built into the reader. In the material experiment, we change three variables as follows: the distance between the book and the reader x (= 50, 100, 200), the relative angle between the book and the reader (φ, θ, ψ) (= 0, 45, 90), and the wave intensity d_i (= 6, 12, 18, 24). In the experiment, the RFID reader emits the wave in 20ms intervals for 4 seconds. RSSI is recorded for each emission. When the reader does not receive a reflected wave, RSSI is recorded as –100. RBF kernel is used in SVM with $\gamma = 0.2$ and cost = 1. We validate the regression model with 10-fold-cross-validation. The evaluation indicators are RMSE and R-squared. RMSE is calculated from formula (1).

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - f_i)^2} \tag{1}$$

where y_i is RSSI obtained in the experiment and f_i is predicted RSSI value.

We calculate the rate of the cases that the RFID reader cannot receive a reflected wave, or when RSSI = –100, as s by using formula (2).

$$S = \frac{q_i}{81} \tag{2}$$

where q_i is the number of cases which the reader cannot detect reflected waves. In the experiment, the variable φ, θ, and ψ have three patterns respectively and the distance between the RFID reader and the tags has three patterns. The denominator of 81 is calculated by multiplying these patterns. The reduction rate of the electrical power consumption E is calcu-

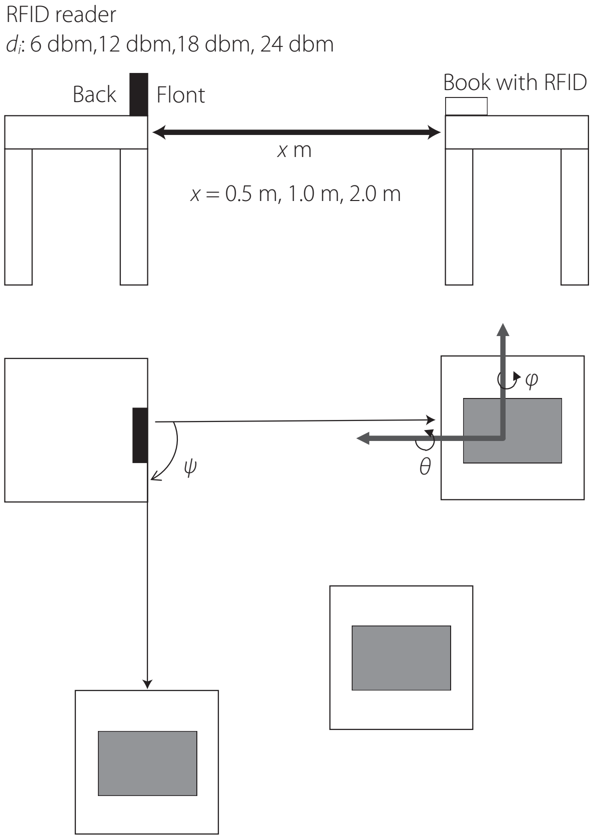

Figure 2: Experiment environment

lated by the ratio of the expected value of the material study and the expected value of maximum wave intensity.

$$E = \frac{\sum_{i=1}^{4} d_i p\,(d_i)}{\max\limits_{i} d_i} \tag{3}$$

where $p(d_i)$ is marginal probability of d_i.

3.2 Experimental results

The prediction by SVM shows RMSE as 7.67 and R-squared as 0.77. Figure 3 shows the frequency of observed RSSI. RSSI is not detected when it is smaller than −80. Figure 4 shows the mean value of RSSI according to the distance. The figure shows that the larger the distance becomes, the smaller RSSI becomes. Friis transmission equation states RSSI is inversely proportional to the square of the distance. The result of the experiment conforms to the equation. We control the wave intensity, the distance and the relative angle. Table 1 shows the value of s calculated by formula (2). Compared to the experiment with distance of 0.5 m, the experiment with distance of 2.0 m results in higher s. Figure 5 shows mean value of RSSI observed for each relative angle. When the RFID reader and the RFID tag are at right angle and hence $\varphi = 90$, $\theta = 0$, and $\psi = 0$, the detection accuracy is the highest. RSSI decreases proportional to θ and ψ. Figure 6 shows the mean value of RSSI observed when the distance between the reader and the tag is 0.5 m. RSSI increases and s decreases propor-

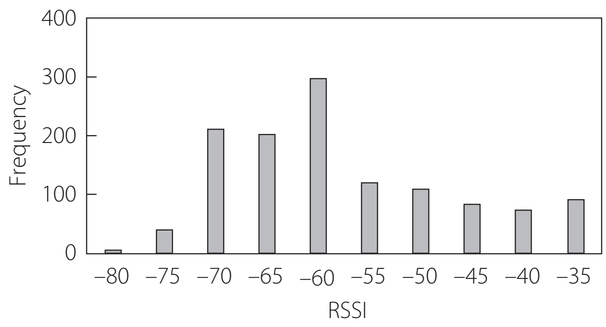

Figure 3: Frequency distribution of RSSI

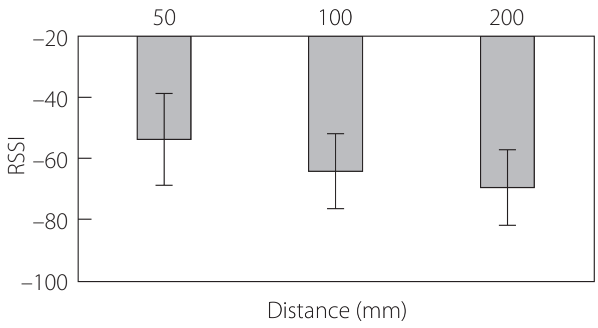

Figure 4 Mean RSSI for different distance between RFID reader and tag

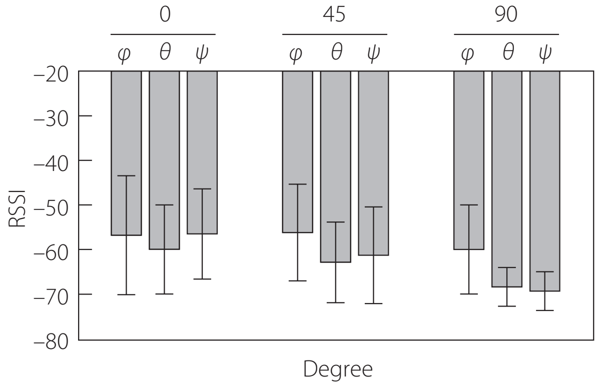

Figure 5: Mean RSSI for different relative angle between RFID reader and tag

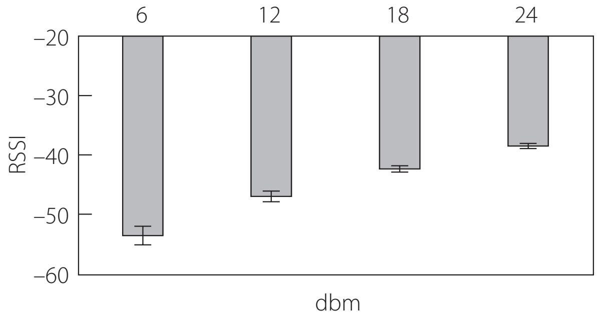

Figure 6: Variance in RSSI for different wave intensity

Table1: Rate of non-detection instances for different wave intensity, distance and relative angle

		6	12	18	24
x	50	0.17	0.15	0.09	0.05
	100	0.22	0.19	0.11	0.01
	200	0.22	0.22	0.17	0.09
φ	0	0.10	0.09	0.05	0.04
	45	0.10	0.10	0.05	0.02
	90	0.10	0.09	0.06	0.01
θ	0	0.10	0.09	0.06	0.01
	45	0.11	0.10	0.06	0.02
	90	0.11	0.10	0.10	0.04
ψ	0	0.17	0.11	0.05	0.01
	45	0.22	0.22	0.11	0.02
	90	0.22	0.22	0.21	0.11

Table 2: Rate of instances detected according to wave intensity

d_i	$p(d_i)$
6 dbm	0.44
12 dbm	0.07
18 dbm	0.15
24 dbm	0.20
>24 dbm	0.14

tional to d_i. Table 2, however, shows required minimum wave intensity changes according to x and (φ, θ, ψ). When the value in Table 2 are substituted in formula (3), the result yields $E = 59$. This shows that when the material study method is used, compared to a case where wave length is always kept at 24 dbm, the wave intensity can be cut to 59 % while maintaining same level of detection accuracy. To conclude, when we choose the wave intensity where predicted value of RSSI is −70 or more and the intensity is minimum, we can develop an intelligent gate which maintains detection accuracy and minimize the electrical power consumption.

4. Conclusion

In this material study, we propose an intelligent gate and validate its effectiveness. The intelligent gate can be developed by training the system with RSSI obtained by the RFID reader and the distance and relative angle between the material and the reader. The distance and the relative angle can be measured by a camera. Hence training data can be obtained automatically. The intelligent gate reduces unnecessary alarm to the user not intending to leave the library. Finally, compared to existing gates, the intelligent gate can reduce the electrical power consumption. In the future, we will investigate how the gate will be influenced when a user goes through the gate with a book in the user's bag or when multiple users go through the gate simultaneously.

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