Automated UHF RFID-based book positioning and monitoring method in smart libraries

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Abstract: In this study, a method is proposed for ultra high frequency radio frequency identification (UHF RFID)-based book positioning and counting developed for smart libraries. In the experimental setup created, RFID tags placed in books were automatically detected using three RFID antennas. Using received signal strength indicator information from each antenna for each book, the locations of the books are determined. In addition, classification was made by using machine learning approaches for the study. For this purpose, the best result for sequence determination in the classification study using ensemble trees, K nearest neighbours (KNN), and support vector machine algorithms was obtained with the ensemble subspace KNN algorithm with 94.1%. The best result for cabinet detection was obtained in the study using the ensemble subspace KNN algorithm and a 78.5% accuracy rate was achieved. The best result for rack detection was obtained with the ensemble subspace KNN algorithm with 95.4%. The study is thought to be useful in the automatic determination of the row, cabinet, and rack of books in smart libraries.

1 Introduction
1.1 Background
In recent years, with the concept of the Internet of Things (IoT), smart systems have begun to provide convenience in all areas of our lives. In addition to many concepts such as smart cities, smart homes, smart hospitals and smart transportation, the IoT has started to be used in smart library systems. Existing library systems have difficulty in providing quality service due to user density. The main purpose of smart library systems is to enable users to be handled more comfortably in the library and to provide library employees with a more stable and quality service.

Technology and services that recognize wireless location play an increasingly important role in people’s lives. RFID is a kind of near field wireless technology that can identify a particular object without direct contact [1]. In recent years, there has been a great technological advance in indoor localisation systems. however, most of the proposals still do not fully solve some problems, such as the time required in the calibration process, poor rigidity, or high installation and equipment costs [2].

1.2 Research motivation
RFID-based library systems in the literature; it consists of three main modules: user-side modules, librarian-side modules, and general modules. Modules on the user side; it consists of six modules: book inquiry, book borrowing-returning, book scanning, book debt payment, use of lockers, and outdoor book return device. Bookrack information is provided both by voucher and by square our lives. In addition to many concepts such as smart cities, smart borrowing device, both book borrowing and returning can be done. This device is planned to be used only for borrowing in a row to eliminate the confusion in the book return process and to collect the books easily. Modules on the librarian’s side; it consists of two main modules: book labelling and book search-sort-count. Book labels can be in the form of both a strip and a regular label. University logo and writings can be written on normal labels. The security of the book can be increased by pasting multiple labels on expensive or important books. General modules used in the library; it consists of two parts: the security system and information screens. When scientific studies in the literature are examined, many smart systems based on RFID have been developed [3–7].

Brian et al. [8] developed an near field communication (NFC)-based smart library system for book tracking. The main purpose of the study is to develop RFID-based book receiving and returning system by using NFC technology on smartphones.

Curran and Norrby [9] proposed an RFID-based location detection method for ambient environments. The method uses the RFID tag to monitor the location of objects or people in the interior. The study ensures that objects or people are tagged with short- and long-distance RFID tags. It is tried to make location determination in the internal environment by obtaining 2D position information. Dhanalakshmi and Mamatha [10] have developed an intelligent library management system. The book management system has been proposed by using ultra high frequency radio frequency identification (UHF RFID) readers located at the entry and exit points of the libraries. Sai Krishna et al. [11] proposed an RFID-based student monitoring and probe system. Bayani et al. [12] have developed an application framework for IoT-based library automation. Choi et al. [13] proposed an RFID-based library system called R-LIM, which facilitates the library book finding process. The positions of the books are determined by constantly reading the antennas placed on the racks and the labels in the books on the racks. The architecture of the book position determination method named R-LIM is given in Fig. 1.

Ting et al. [14] have developed a method for location detection using passive RFID tags for indoor environments. In the proposed method, the existing indoor environment is divided into certain matrices and the RFID antennas in the environment are deployed. Location determination is made by using the tag information read from RFID antennas. For experimental results, the results were obtained by performing tests on an area of 3 m × 3 m. Xu et al. [15] proposed a method for indoor RFID-based location detection using the K nearest neighbour algorithm and Bayes classifier. RSSI values from the tags are read using RFID antennas. The properties obtained are determined using the nearest neighbour algorithm K and Bayes classifier. In the study, results were obtained by using
different numbers of labels in an experimental environment. Chen and Luo [16] have developed a WiFi-based location detection method. Information from WiFi-based tags is transferred to access points on the local network. In this way, a local experimental environment is created and the location is determined together with the data received from more than one node. Shangguan et al. [17] proposed a method for creating spatial–temporary phase profiles for relative RFID tag placement. In this study, reader antennas move on the current area and obtain RSSI and phase values from the tags. Using these values, tests were made for five different scenarios, and results were given. There are many different methods in the literature for location detection and tracking using RFID and other technologies [18–24].

1.3 Literature review
The recent studies in the literature in this area are summarised in Table 1.

1.4 Our method
The method proposed in this study is summarised in Fig. 2.

1.5 Study outline
In Section 2 of the study, information about the experimental environment is given. The number of books in the library environment and the features of the RFID tools used is given. In Section 3 the features of the data set and the proposed method are explained. In Section 4 classification results and method performance are explained. In Section 5 confusion matrices of classification results are given. The advantages of the study are explained. In Section 6 the results, and future studies are explained in Section 7.

1.6 Contributions and novelties
Contributions and novelties summary of the proposed method are:

• In this study, a new method for UHF RFID-based book location detection developed for smart libraries is proposed.
• For the proposed method, a data set was created using 446 books, and the literature was contributed.
• The machine learning-based method using RSSI data for book location detection is proposed.
• In the proposed method, success was 94.1% for row detection, 78.5% for cabinet detection, and 95.4% for rack detection.

2 Materials
In this study, an experimental environment was created by taking the book cabinets in an existing library system as an example. In the experimental setup, there are two rows of cabinets, three cabinets in each row, and four racks in each cabinet. In the experimental environment, there are a total of 202 book RFID labels during the first cabinet and a total of 244 book RFID labels during the second cabinet. In the experimental environment, a total of 446 RFID labels, 3 antennas, and 1 reader were used. According to the experimental setup created, the number of books on the racks is given in Table 2.

MTI Wireless Edge 242014 antenna, Impinj Speedway Revolution R420 UHF brand reader was used in the experimental setup established to test the proposed method. General characteristics of the antenna and reader are given in Fig. 3.

The proposed method was run in MATLAB environment and ensemble trees, K nearest neighbours (KNN), and support vector machine (SVM) classification results were obtained. Classification learner toolbox was used in the MATLAB program for the classification process. A data set was created in the library environment. When classifying on the dataset, a ten-fold cross was made. Training and test data were selected using ten fold crossing.

3 Proposed method
In this study, a method is proposed for locating and tracking books quickly within the library. As a method, primarily UHF RFID antenna, reader, and tags left in the book are used. The
The experimental setup for testing the proposed method was created as shown in Fig. 4.

As shown in Fig. 4, there are two rows in total in the experimental setup. There are three cabinets in each row and four racks in each cabinet. The steps of the proposed method are as follows:

1. Reading RFID tags from three antennas and transferring them to the computer.
2. Editing the tag information stored on the computer.
3. Determining the row of the book according to RSSI values.
4. Determining in which cabinet the book is in the determined row.
5. Determining which rack the book is in the detected cabinet.

Information coming to the antennas is used to determine the position of the book. In this study, a library environment was created using 2 rows × 3 cabinets × 4 rack. A total of 446 books were tagged for 2 rows × 3 cabinets × 4 rack using 3 RFID antennas. If the library had a different number of shelves such as 10 rows × 5 cabinets × 5 racks, the number of antennas would increase.

In the experimental setup presented in Fig. 4, three RFID antennas were used. RFID antennas are labelled as numbers 1, 2, and 3. When the experimental results obtained were examined, it was seen that the antenna number 3 was insufficient in determining the position, and the antennas numbered 1 and 2 were more effective in determining the position. For this reason, two antennas...
should be fixed between each row in the library environment, on the left and right sides.

Book location detection can be done successfully by using 18 antennas in total for 10 rows libraries. The number of rows and the number of antennas are proportional to each other. The relationship between the number of rows and the number of antennas is given in (1)

\[
\text{Number of antennas} = 2 \times (\text{Number of rows} - 1) \tag{1}
\]

In the proposed method, the RFID tags of the existing books are read from three antennas in the first step. ‘ReadCount’, ‘Min RSSI’, ‘RSSI’ and ‘Max RSSI’ values of the detected tags are read. Here, the value of ‘ReadCount’ is the number of tag reads by the antenna. The program used to read the label continuously reads the labels while it is running. RSSI information for each tag is.

Fig. 3 General features of the antenna and reader

Fig. 4 Experimental setup used in the proposed method
obtained. If the label is read more than once, ‘Min RSSI’ and ‘Max RSSI’ values are obtained. A total of 12 features are obtained by using three antennas for a label. A data set was created by reading the labels for all books. The features have been made meaningful by pre-processing on the data set obtained. For the ‘ReadCount’ value obtained from each antenna, standard deviation and average are calculated as in (2) and (3). Then, as in (4), a threshold value was created by taking the difference between the mean value and the standard deviation.

**Mean:**

\[ f_{\text{mean}} = \frac{\sum_{i=1}^{N} X_i(\text{ReadCount})}{N} \]  

(2)

**Standard deviation:**

\[ f_{\text{std}} = \sqrt{\frac{\sum_{i=1}^{N} (X_i(\text{ReadCount}) - f_{\text{mean}})^2}{N}} \]  

(3)

**Threshold:**

\[ T = (f_{\text{mean}} - f_{\text{std}}). \]  

(4)

Using (2)–(4), feature extraction is made on the existing 12-feature dataset. The pseudocode of the pre-processing algorithm developed for feature extraction is given below.

The purpose of using the pre-processing algorithm is to get more than one data from three antennas for each tag. Thus, ‘Min RSSI’ and ‘Max RSSI’ values have been made more stable. The rate of success increases as a result of the pre-processing algorithm.

As seen in Table 4, nine different classification scenarios were created on the data set. Firstly, row determination was made using the RSSI features taken from three antennas, the order in which the book is attached is

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**Table 3. Parameters of proposed classification methods**

| Method                  | Ensemble Method | Learner Type | Maximum number of splits | Number of learners | Learning rate | Subspace dimension |
|-------------------------|-----------------|--------------|--------------------------|--------------------|---------------|-------------------|
| Ensemble bagged trees   | ensemble bagged | decision tree | 495                      | 30                 | 0.1           | 1                |
| Ensemble RUSBoosted trees | ensemble RUSBoost | decision tree | 20                       | 30                 | 0.1           | 1                |
| Ensemble subspace KNN   | ensemble subspace KNN | nearest neighbours | 20                   | 30                 | 0.1           | 5                |
| Medium KNN              |                  |              |                          |                    |               |                  |
| SVM quadratic           |                 |              |                          |                    |               |                  |
| SVM cubic               |                 |              |                          |                    |               |                  |
There are two classes here. The book is either in row 1 or row 2 in the experimental environment. Then, classification was made on all book labels in row 1. In the last step, it is determined in which book 1, cupboard 2, and cupboard 3 in row 1. Similarly, classification was made among the books in row 2. Then the racks in the existing cabinets are classified. By looking at the label information read, it is determined on which rack the book is in the current cabinet.

These classification results were obtained using ensemble trees, KNN, and SVM algorithms. The best classification success rates for nine different scenarios are shown in Table 5. Accuracy, Recall, Precision, and F-measure values are calculated to measure the success of the results obtained after the classification process. Accuracy, Recall, Precision, and F-measure values were calculated as in (5)–(8), respectively:

\[
\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN} \quad (5)
\]

\[
\text{Recall} = \frac{TP}{TP + FN} \quad (6)
\]

\[
\text{Precision} = \frac{TP}{TP + FP} \quad (7)
\]

\[
F\text{-measure} = \frac{2(\text{Recall} \times \text{Precision})}{(\text{Recall} + \text{Precision})} \quad (8)
\]

The best classification algorithm is shown for nine scenarios in Table 4. Accuracy, Recall, Precision, and F-measure values were calculated by running 100 best iterations for each scenario. Then, after 100 iterations, the best result (Best), the average result (Mean), and standard deviation result (Std) for Accuracy, Recall, Precision, and F-measure values were calculated. The results obtained for nine scenarios are given in Table 5.
Discussions
The discussions of the proposed method are given below. In this study, nine scenarios were created to test the proposed method. First of all, a library environment was created and one reader and three antennas were used. Data set with RSSI and other values from RFID tags were created using 446 books in total. In the created library environment, there are two rows, three cabinets in each row, and four racks in each cabinet. Row detection, cabinet detection, and rack detection were performed using ensemble trees, KNN, and SVM algorithms. Confusion matrix results obtained according to the classification results are given in Fig. 6.

In his study, Chen and Luo [16] developed a method for searching for books using the handheld terminal for finding books in the library. For book detection, it is necessary to constantly visit the library with the handheld terminal. It cannot determine whether the book is in the correct position. Ajana et al. [18] used the closest neighbour algorithm and Bayesian classifier K for RFID-based location detection in the indoor environment. It determines the location according to RSSI data received from RFID tags placed on the ground. In this study, no library environment was created and success results were not calculated.

In Table 6, the proposed method shows the separate structure of the row, cabinet, and rack detection. Also, the results of the proposed method appear to be better than the studies in the literature.

| Reference                        | Method                                         | Accuracy | Precision | Recall | F-measure |
|----------------------------------|-----------------------------------------------|----------|-----------|--------|-----------|
| Moreno-Cano et al. [2]           | artificial neural networks                     | 65       | —         | —      | —         |
| Sue and Lo [7]                   | book locating system – single book mode        | 90       | —         | —      | —         |
|                                  | book locating system – book list mode          | 85       | —         | —      | —         |
| Dhanalakshmi and Mamatha [10]    | library management system                      | 87       | —         | —      | —         |
| Ting et al. [14]                 | indoor positioning system                      | 93       | —         | —      | —         |
| Xu et al. [15]                   | Bayesian and K-nearest neighbour               | 88       | —         | —      | —         |
| Shangguan et al. [17]            | STPP                                           | 96       | —         | —      | —         |
|                                  | OTrack                                         | 88       | —         | —      | —         |
|                                  | G-RSSI                                         | 51       | —         | —      | —         |
| Bu et al. [27]                   | RF-3DScan                                      | 92.5     | 92        | 92     | —         |
|                                  | STPP                                           | 82.5     | 87.5      | 84     | —         |
| Cheng et al. [29]                | deep learning                                  | 92.4     | —         | —      | —         |
| Xue et al. [30]                  | hyperbolic and hologram localisation algorithm | 92.4     | —         | —      | —         |
| our methods                      | row detection – ensemble subspace KNN           | 94.17    | 94.25     | 94.05  | 94.15     |
|                                  | cabinet detection – ensemble subspace KNN      | 78.57    | 78.46     | 78.73  | 78.59     |
|                                  | rack detection – ensemble subspace KNN         | 95.45    | 95.24     | 95.83  | 95.53     |

5 Discussions
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The advantages of the proposed method are given as follows:

- Since the books are arranged adjacent to the library environment, position determination becomes difficult. Determining the book position in the proposed method showed that the study was original.
- When the studies in the literature are analysed, there are no studies that detect row, cabinet, and rack. In this study, the
position of the book (row, cabinet, and rack) has been determined successfully.

• Three classification algorithms are used for position determination. High classification success (Accuracy, Recall, Precision, and F-measure) was achieved with the proposed methods.

• The developed method can work in real-time.

• By detecting misplaced books, it can show the real position of the book.

6 Conclusions
With the smart library technology, operations such as book scanning, borrowing, returning, and counting of books are carried out easily for library employees and users. The counting, borrowing, returning and book security of books are done more successfully by using RFID tags. HF and UHF RFID systems are preferred for library systems. In this study, a method for UHF RFID-based book positioning is proposed for smart libraries. By using UHF RFID antennas and readers, ID and RSSI values of the labels affixed to the books are read. RSSI information is matched by reading from three different antennas located in different locations for a tag. Then, feature extraction was made from these data. The classification was made using the data set obtained as a result of feature extraction. While classifying, MATLAB Classification Learner Toolbox was used. Results were obtained using the ensemble trees, KNN, and SVM algorithms for the classification process. As a result of the classification, it was seen that the best result for the row of the books was 94.1%, the best result for the cabinet detection was 78.5% and the best result for the rack detection of the books was 95.4%. When the studies in the literature are examined, no study determines the book position using RSSI values. This revealed that the study suggested an original and new method. Also, the proposed method provides great convenience for library users and employees.

7 Future work
In this study, a data set was created using 446 books. In the next study, it is aimed to increase the success of the method to 100% by using deep learning-based methods. In future studies, a large data set will be created by increasing the number of books that are insufficient for deep learning. Many antennas and readers should be used in the library environment. In this case, it is costly. In future studies, an autonomous robot will be developed to reduce the cost and the method will be developed using one antenna and a reader on the robot. Thus, a low-cost system can be developed and used for the entire library in real-time. In the next study, it is aimed to test the method that will be developed by using at least 10,000 books in a real library environment.

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9 References
[1] Chen, Z., Wang, C.: ‘Modeling RFID signal distribution based on neural network combined with continuous ant colony optimization’, Neurocomputing, 2014, 123, pp. 354–361
[2] Moreno-Canov, M.V., Zamora-Izuquierdo, M.A., Santa, J., et al.: ‘An indoor localization system based on artificial neural networks and particle filters applied to intelligent buildings’, Neurocomputing, 2013, 122, pp. 116–125
[3] Bansode, S.Y., Desale, S.K.: ‘Implementation of RFID technology in University of Pune Library’, Program, 2009, 43, (2), pp. 202–214
[4] Jin, X.-B., Dou, C., Su, T., et al.: ‘Parallel irregular fusion estimation based on nonlinear filter for indoor RFID tracking system’, Int. J. Distrib. Sens. Netw., 2016, 12, (5), p. 1472930
[5] Chapter 1: ‘Library RFID systems for identification, security, and materials handling’, Libr. Technol. Rep., 2012, 48, (5), pp. 9–16
[6] Younis, M.I.: ‘SLMS: a smart library management system based on an RFID technology’, Int. J. Reason.-Based Intell. Syst., 2012, 4, (4), p. 186
[7] Sue, K.-L., Lo, Y.-M.: ‘BLOCS: A smart book-locating system based on RFID in libraries’, 2007 Int. Conf. on Service Systems and Service Management, Chengdu, China, 2007, pp. 1–6
[8] Brian, A.L., Arokiam, L., Malarcheli, D.P.S.K.: ‘An IoT based secured smart library system with NFC based book tracking’, Int. J. Emerg. Technol. Comput. Sci. Electron. (IJETCSE), 2011, 11, (5), pp. 18–21
[9] Curran, K., Norby, S.: ‘RFID-enabled location determination: within indoor environments’, Int. J. Comput. Intel., 2009, 1, (4), pp. 63–86
[10] Dhanalakshmi, M., Mamatha, U.: ‘RFID based library management system’, Proc. of ASCNT'09, pp. 24–25
[11] Sai Krishna, C., Sumanth, N., Raghava Prasad, C.: ‘RFID based student monitoring and attendance tracking system’. 2013 Fourth Int. Conf. on Computing, Communication and Networking Technologies (ICCCNT), Tiruchengode, India, 2013, pp. 1–5
[12] Bayani, M., Segura, A., Alvarado, M., et al.: ‘IoT-based library automation & monitoring system: developing an implementation framework’, E- Ciencias de la Inf., 2017, 8, (11), pp. 83–100
[13] Choi, J.-W., Oh, D.-J., Song, I.-Y.: ‘RFID: An affordable library search system based on RFID’. 2006 Int. Conf. on Hybrid Information Technology, Cheju Island, South Korea, 2006, pp. 71–74
[14] Ting, S.L., Kwock, S.K., Tsang, A.H.C., et al.: ‘The study on using passive RFID tags for indoor positioning’, Int. J. Eng. Bus. Manage., 2011, 3, (1), p. 8
[15] Xu, H., Ding, Y., Li, P., et al.: ‘An RFID indoor positioning algorithm based on Bayesian probability and K-nearest neighbour’, Sensors (Switzerland), 2017, 17, (8), pp. 1–17
[16] Chen, Y., Luo, R.: ‘Design and implementation of a WiFi-based local locating system’. 2007 IEEE Int. Conf. on Portable Information Devices, Orlando, FL, USA, 2007, pp. 1–5
[17] Shangguan, L., Yang, Z., Liu, A.X., et al.: ‘STPP: spatial-temporal-phase profiling-based method for real RFID tag localization’, IEEE/ACM Trans. Netw., 2017, 25, (1), pp. 596–609
[18] Ajana, M.E., Harroud, H., Boulmalf, M., et al.: ‘FlexRFID: a flexible middleware for RFID applications development’. 2009 IFIP Int. Conf. on Wireless and Optical Communications Networks, WOCN 2009, Cairo, Egypt, 2009, pp. 1–5
[19] Zhang, M., Li, W., Wang, Z., et al.: ‘A RFID-based material tracking information system’. Proc. of the IEEE Int. Conf. on Automation and Logistics, ICAL 2007, Jinan, China, 2007, pp. 2922–2926
[20] Xiaoming, Q., Zhi, N.C., Ailian, C.: ‘Multi-loop antenna for high frequency RFID smart shelf applications’, IEEE Sensors, 2007, 7, pp. 5467–5470
[21] Al-Ali, A.R., Alsol, F.A., Aji, N.R., et al.: ‘Mobile RFID tracking system’. 2008 3rd Int. Conf. on Information and Communication Technologies: From Theory to Applications, ICTTA, Damascus, Syria, 2008, pp. 9–3
[22] Michael, M.P., Darianian, M.: ‘Architectural solutions for mobile RFID services for the internet of things’. Proc. – 2008 IEEE Congress on Services, SERVICES2008, Honolulu, HI, USA, 2008, PART I, pp. 71–74
[23] Yassin, A., Nasser, A., Awad, M., et al.: ‘Recent advances in indoor localization: a survey on theoretical approaches and applications’, IEEE Commun. Surv. Tutor., 2017, 19, (2), pp. 1327–1346
[24] Lai, B.P.L., Marakkalage, S.H., Zhon, Y., et al.: ‘A survey of data fusion in smart city applications’, Inf. Fusion, 2019, 52, (May), pp. 357–374
[25] Shen, L., Zhang, Q., Pang, J., et al.: ‘PKDL: relative localization method of RFID tags via phase and RSSI based on deep learning’, IEEE Access, 2019, 7, pp. 20249–20261
[26] Tags, R., Shen, L., Zhang, Q., et al.: ‘ANTopIn: Efficient Absolute Localization Method of RFID Tags via Spinning Antenna’, Sensors, 2019, 19, (4), pp. 1–20
[27] Bu, Y., Xie, L., Gong, Y., et al.: ‘RF-3DScan: RFID-based 3D reconstruction on tagged packages’, IEEE Trans. Mob. Comput., 2019, pp. 1–1. doi: 10.1109/TMC.2019.2943853
[28] Shi, W., Du, J., Cao, X., et al.: ‘IKULADS: an improved kNN-based UHF RFID indoor localization algorithm for directional radiation scenario’, Sensors (Switzerland), 2019, 19, (4), pp. 1–18
[29] Cheng, S., Wang, S., Guan, W., et al.: ‘3DLRA: an RFID 3D indoor localization method based on deep learning’, Sensors (Switzerland), 2020, 20, (9), pp. 1–16
[30] Xue, F., Zhao, J., Li, D.: ‘Precise localization of RFID tags using hyperbolic and hologram composite localization algorithm’, Comput. Commun., 2020, 157, (April), pp. 451–460