Performance of RFID Tags used in Automated Retail Store

(IJCSNT) International Journal of Communication Systems and Network Technologies
ISSN Number: 2053-6283
Volume 2, Issue No. 2, 63–79

https://journals.mirlabs.in/index.php/ijcsnt
DOI-10.18486/ijcsnt/2.2.023

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Abstract

In recent times the applications of Radio Frequency Identification (RFID) technology have started emerging in diverse areas comprising access control, inventory management, supply chain management, equipment tracking, personnel tracking, toll collection, and items security in departmental stores. An important application that holds great promise in future is in big retail stores where RFID tagged items can be billed automatically at the Point of Sales thereby eliminating the long queues that are observed especially on weekends. In this paper we present the design and development of an automated retail store based on RFID. We further perform experiments on different types of RFID tags that can be used for tagging the items in retail stores to compare their performance and applicability. It is observed that the use of RFID tags in retail stores improves the efficiency, accuracy and security at the point of sales and the proposed system can be easily adopted in modern retail stores without incorporating many changes in the existing infrastructure.

Keywords

Radio Frequency Identification (RFID) Tags, Retail Store, Item Tracking

Received: 24 April 2013; **Revised:** 31 July 2013; **Accepted:** 11 August 2013;
Published: 31 August 2013;

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Introduction

RFID stands for Radio Frequency Identification which provides the ability to Identify, Locate, and Sense the Conditions of animate and inanimate entities.

Radio frequency identification, or RFID, is a generic term for technologies that are used for auto-identification of people or object using radio waves. In this technology a unique serial number is stored to identify a person or an object and other related information, on a microchip of Silicon that is attached to an antenna which in turn is attached to a RFID reader also called as interrogator. The antenna enables the chip to transmit the identification information to a reader then the reader converts the radio waves reflected back from the RFID tag into digital information that can then be passed on to computers running RFID application middleware, that can make use of it [1,2].

Advantages over Bar Code

RFID Electronic Product Code (EPC) is now seen as a successor to the optical barcode. It is observed that most of the applications of optically readable barcode can be performed using RFID tags with certain distinct advantages [3]. Some of these advantages are:

- Bar codes are based on line-of-sight technology i.e., a user has to orient the bar code towards the scanner for it to be read. In contrast, Radio frequency identification doesn't require line of sight [5,6]. RFID tags can be read as long as they are within range of a reader. While an item in a retail store must be passed over a scanner with its barcode clearly exposed, an RFID tag may be scanned just by being placed in the vicinity of a reader.
- In bar codes, if the label is soiled or ripped or peeled off, there is no way to scan the item.
- Standard bar codes identify only the manufacturer and product, not the unique item. Generally, bar codes are identical for the complete batch of identical items in a store. It is thus possible to pass on a carton of milk well past its date of expiry as every carton of milk is same as the other in the lot [7,8]. In RFID every box has unique identification number; therefore product distribution can be accurately controlled. The unique identifiers in RFID tags can act as pointers to database entries containing rich transaction histories for individual items [9].
- An RFID reader is typically capable of scanning hundreds of RFID tags simultaneously which is simply impossible in barcode technology where every item is to be scanned separately. This means extra efficiency, time saving and accuracy in the handling of items [1,2,4].

Components of RFID System

The RFID system comprises an RFID Reader that is connected to an antenna which in turn senses the tags present in the vicinity (Figure 1). The RFID Reader is connected to the host computer. Multiple such readers can be connected to the host computer if necessary [15,16,24,25].

- Tags or EPCs are attached to objects/items in RFID solutions. Tags have unique ID and are used for identification of the objects/items [10].
- Antenna is attached to the reader which is used for reading tags. Antenna has its own magnetic field and tags can be only read within these magnetic fields.
- Reader works for handling antenna signals and manipulate tags' information.

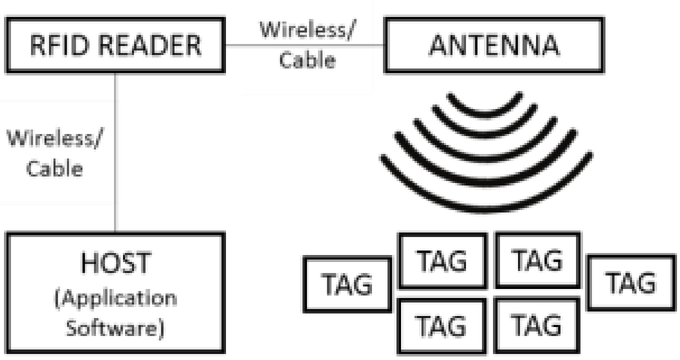

Figure 1. Components of Radio Frequency Identification System

- Communication infrastructure may be used for reader to communicate with IT infrastructure and work as middle layer between application software and reader.
- Application software is run on the host computer and it enables user to see RFID information. It can comprise a database, application routines or simply user interface.

Proposed Work

The entire system developed during this work can be represented by means of a 3-tier architecture, whose components are namely RFID Hardware, Middleware, and Application framework[11,12].

RFID Hardware consists of readers and tags. Here, readers act as a first of contact to the tags. The middleware provides an interface to the application for accessing the RFID hardware. Application framework utilizes the various services provided by the middleware to enable the application developers develop different kinds of RFID application[13,14].

Stores may be on residential streets, shopping streets with few or no houses or in a shopping mall. Shopping streets may be for pedestrians only. Shopping generally refers to the act of buying products. Sometimes this is done to obtain necessities such as food and clothing[17].

End-user can purchase goods and services as individuals or businesses from the Retail Store. Moreover retailers are part of an integrated system called the supply-chain[18]. A retailer purchases goods or products in large quantities from manufacturers or directly through a wholesaler, and then sells smaller quantities to the consumer for a profit. Retailing can be done in either fixed locations or online. The term “retailer” is also applied where a service provider services the needs of a large number of individuals, such as a public utility, like electric power[9,24].

Current retail Store management systems use barcode technology and security strips. Using barcodes, a management system can keep records of purchases items such as soaps, cakes, toothpaste, biscuits, etc. Security strips on retail items tag their movements[4].

Barcodes and security strips have their limitations as they are slow to read; they must be kept into the correct orientation towards the reader to read. Any damage, such as ripping or soiling will make the process of reading impossible[19]. Readers in this case are only capable to handle items one by one which is time consuming and frustrating in peak hours [20]. Many a times at the peak hours, buyers visit the retail shops at the same time which will require waiting in the queue for their turn at the point of sale, which may also lead to chaos due to the mismanagement under limited resources. Also barcodes and security strips are prone to sabotage. All these lead to considerable loss in efficiency and incorrect assessment of valuable inventory [24].

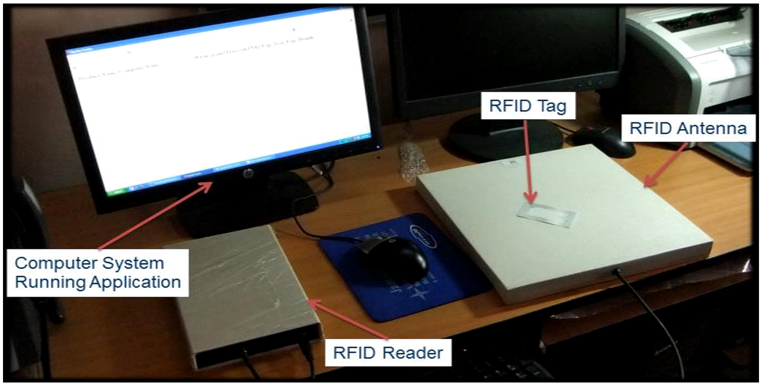

Figure 2. System Setup in Laboratory

In the proposed RFID framework, an application for Future Retail Store is developed, which will provide a greater amount of efficiency and error free functioning. It will ensure that there is quick check-in/check-out of items for convenience of buyers; quick and correct shelving of items in the inventory; prevention of thefts; and quick inventory checks [21].

To accomplish above mentioned goals we have attached RFID tag to each items in our proposed Retail Store. We installed RFID reader to read the attached tags. An application is developed that automatically updates the store resources in web server i.e. remove the item/s from the store once the buyer purchased that item/s and generate bill at the point of sale [22]. Another application runs on a number of computer systems in the Retail Store that will provide the details of the items like price, quantity, date of manufacture, date of expiry etc. to the customer when required by the customer.

This system will overall improve visibility of products in supply chain, reduce ’out-of-stocks’ situations and maintain ’safety stocks’; more accurately tracks inventory in stock, reduce manual inventory management tasks, identify and reduce shrinkage. Real-time product monitoring reduces warehouse shrink and administrative errors, improve management and visibility of reusable assets across the supply chain, improve responsiveness to product recalls. It will also provide better authentication of products against counterfeiting, it will help in checking spurious goods, ensuring the right mix of products on the floor, etc. This would lead to improved customer satisfaction, quality of shopping experience and security of goods [23].

Design Details

A number of API functions are used by the proposed Framework that can be classified as General operations, operations for Administrator, and operations for End-user/Customer. These functions with their parameters and return values are listed below:

General Operations:

General operations will perform basic operation with the Reader.
a) Check Reader Connection: This command will check whether reader is connected to computer or not.
Syntax: `BOOL CheckReaderConnection (VOID);`
Parameters: No Parameters
Return Value: If the Reader is connected to the Computer, the function will return TRUE otherwise it will return FALSE.
b) Get Reader Information: This command gets the information related to Reader Serial Number, Software version and Hardware version from the reader if it is connected to the computer.
Syntax: `BOOL GetReaderInformation (CHAR strSwVersion [ ], CHAR strHwVersion [ ], CHAR strSerialNo [ ]);`
Parameters: strSwVersion: This parameter returns the Software Version of the Reader. If the passed value is NULL, Software Version will not be returned. strHwVersion: This parameter returns the Hardware Version of the Reader. If the passed value is NULL, Hardware Version will not be returned. strSerialNo: This parameter returns the Serial Number of the Reader. If the passed value is NULL, Serial Number will not be returned.
Return Value: If the Reader Information is found successfully, the function will return TRUE otherwise it will return FALSE.

Operations for Administrator:

These operations are performed by the administrator to enter each and every item in the store one by one with its product name, company name, size, price, mfg date, expiry date, ingredients etc. After these operations all information pertinent to an item gets associated with its unique tag ID (EPC code).

StartEntryMode function will set the Reader in continuous inventory mode. If any tag is detected, the Reader will send a LoopEntryMode Request with the Unique Identifier of the detected tag to the Host Application. Once the Application has the Unique Identifier of the tag, it will ask the User to enter further details. Once any Tag is detected by the Reader in Entry Mode, the Reader will only start detection of new Tags after one of these two conditions. First condition is if the process for storing the data in the detected Tag is complete and second one is the Reader sends the positive or negative confirmation to the Application and the last one is if the Application sends the StopEntryMode Function to the Reader. If these function do not encounter any error they return TRUE value else FALSE. The parameter bError returns the error code if there is any error occurring in the function. If the function is successfully executed, the value of bError will be 0.
a) Start Entry Mode: This function will inform the Reader to start automatic continuous inventory sequence in the reader.
Syntax: `BOOL StartEntryMode (BYTE* bError);`

Parameters: bError: It returns the error code if there is any error occurred in starting the Entry Mode process. If the Entry Mode is started successfully, the value of bError will be 0.
Return Value: If there is any problem starting the Entry Mode, the function will return FALSE otherwise it will return TRUE.
b) Stop Entry Mode: This function will stop the continuous inventory of the tags in the reader.
Syntax: `BOOL StopEntryMode (BYTE* bError);`
Parameters: bError: bError returns the error code if there is any error occurred in stopping the Entry Mode process. If the Entry Mode is stopped successfully, the value of bError will be 0.
Return Value: If there is any problem stopping the Entry Mode, the function will return FALSE otherwise it will return TRUE.
c) LoopEntryMode: This function will give the Unique Identifier of the Tag if any Tag is available in the range of the Reader.
Syntax: `BOOL LoopEntryMode (BYTE* bTagType, CHAR strUID [ ], BYTE bUID [ ], BYTE* bUIDLen, BYTE* bError);`
Parameters: bTagType: This parameter returns the type of the Tag available in the range of the Reader. strUID: strUID returns the Unique Identifier of the Tag found near the Reader in string format. Passed string must have space to store minimum 25 characters. bUID: bUID is an array of minimum 20 Bytes which returns the Unique Identifier of the Tag found near the Reader if any in binary format. If the value of Unique Identifier is not required in Binary format, NULL can be passed. bUIDLen: bUIDLen returns the number of bytes stored in bUID array by the function. bError: bError returns the error code if there is any error occurred in detection of the Tag. If the Tag is detected successfully, the value of bError will be 0.
Return Value: If the Tag is detected successfully, the function will return TRUE otherwise it will return FALSE.

Operations for End-user/Customer:

This mode of operations is designed for the End-user/Customer which provides information of the item to the customer. These operations are also designed for quick check-in/check-out of items for convenience of buyers, quick and correct shelving of items in the inventory, complete prevention of thefts, quick inventory check.

To start these operations, user has to configure the Reader in Table Mode. Once the reader configuration is successful, the continuous detection of items started when the customer passes through the Reader and Polling Mode is started automatically and a timer started. When the timer is out, the reader will stop detection of tags for that customer and Polling Mode will be stopped automatically. After that receipt for the items will be generated and information will be updated on the web server.
a) Start Table Mode: This function will inform the Reader to start Table Mode processes.
Syntax: `BOOL StartTableMode (BYTE* bError);`
Parameters: bError: bError returns the error code if there is any error occurred in starting the Table Mode process. If the Table Mode is started successfully, the value of bError will be 0.
Return Value: If there is any problem starting the Table Mode, the function will return FALSE otherwise it will return TRUE.
b) Stop Table Mode: This function will tell the Reader to stop the Table Mode.
Syntax: `BOOL StopTableMode (BYTE* bError);`

Parameters: bError: bError returns the error code if there is any error occurred in stopping the Table Mode process. If the Table Mode is stopped successfully, the value of bError will be 0.

Return Value: If there is any problem stopping the Table Mode, the function will return FALSE otherwise it will return TRUE.

c) Start Polling Table Mode: This function will start the continuous polling for Tags.

Syntax: `BOOL StartPollingTableMode (BYTE bTagType, BYTE* bError);`

Parameters: bTagType: bTagType parameter is used by the Reader for starting the continuous polling for specific type of Tags. bError: bError returns the error code if there is any error occurred trying to start polling for Tags. If the process is completed successfully, the value of bError will be 0.

Return Value: If there is any problem starting continuous polling of Tags, the function will return FALSE otherwise it will return TRUE.

d) Stop Polling Table Mode: This function will stop the continuous polling started using StartPollingTableMode.

Syntax: `BOOL StopPollingTableMode (BYTE* bError);`

Parameters: bError: bError returns the error code if there is any error occurred trying to stop polling. If the process is completed successfully, the value of bError will be 0.

Return Value: If there is any problem stopping continuous polling, the function will return FALSE otherwise it will return TRUE.

e) Loop Table Mode: Loop Table Mode will give the Unique Identifier of the Tags available in the range of the Reader.

Syntax: `BOOL LoopTableMode (BYTE bMaxTags, BYTE* bTags, BYTE bTagType[], CHAR strUID [ ], BYTE bUID[][20], BYTE bUIDLen[], BYTE* bError);`

Parameters: bMaxTags: It indicates the maximum number of Tag data the passing arrays can handle. The minimum value for this parameter must be greater than 10 for good performance. bMaxTags: The function will return the total number of Tags detected by the Reader in this parameter. bTagType: This array returns the type of all the Tags detected by the Reader. Minimum length of this array must be equal to bMaxTags parameter. strUID: strUID returns the Unique Identifier of all the Tags found near the Reader, in string format. All the Unique Identifiers are stored in this single string separated by semicolon (";") character. Passed string must have space to store minimum 25 characters for one Tag i.e. the length of the string must be minimum (bMaxTags * 25). bUID: bUID is a two dimensional array with 20 as its second dimension. Its minimum value for first dimension must be equal to bMaxTags parameter. It returns the Unique Identifier of all the Tags found near the Reader in binary format. If the value of Unique Identifier is not required in Binary format, NULL can be passed. bUIDLen: bUIDLen returns the number of bytes stored for each Unique Identifier stored in bUID array. bError: bError returns the error code if there is any error occurred in detection of the Tags. If the Tags are detected successfully, the value of bError will be 0.

Experiments and Results

Experiments were performed on four types of tags depicted in Figures 3(a), 4(a), 5(a) and 6(a). The tags were procured from industry to develop the Future Store application. The setup comprised a High Frequency (HF) Reader and experiments were performed on number of tags of each category. The tags were affixed to different retail items such as soaps, snacks, toothpaste, bottles etc. in the proposed Future Store (Fig. 14).

The group of items was then passed through the reader. The items were read by the reader with certain constraints. First of all we experimented with RFID tags of Type-I (Fig 3(a)). We experimented by varying the number of tags in increasing order and then observed the number of tags read by the reader. Further we took combination of different types of tags and determined their readability.

Figure 3. RFID Tag Type-I

On performing experiments we observed following results as shown in Table 1. The results are depicted in Figure 3 (b) by plotting a graph between the number of Tags/Items and % read of Tags.

Table 1. Experiment Result with RFID Tag Type – I

No. of Tags	Average No. of Tags Read
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	7.8
9	8.6
10	9.4

Similarly, we experimented with RFID Tag Type-II as shown in Fig 4(a).

We observed following results on performing experiments with RFID Tag Type-II as shown in Table 2 and Fig 4(b).

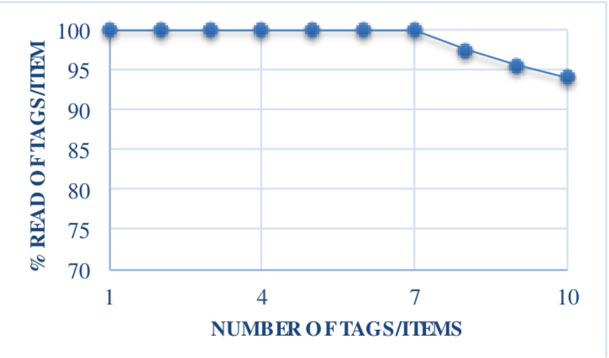

Figure 4. Experiments performed with RFID Tag Type-I

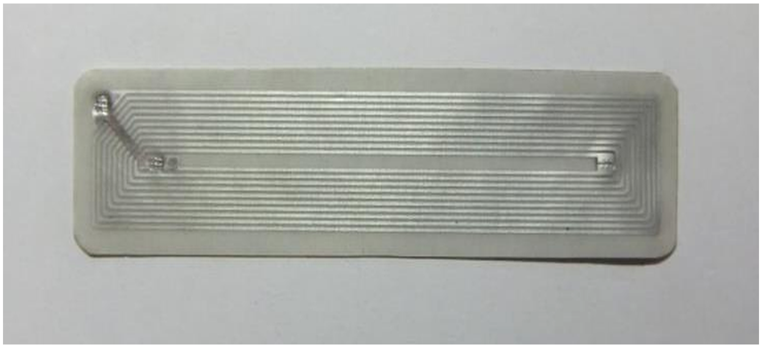

Figure 5. RFID Tag Type-II

Table 2. Experiment Result with RFID Tag Type – II

No. of Tags	Average No. of Tags Read
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10

Similarly, we experimented with RFID Tag Type-III as shown in Fig 5(a).

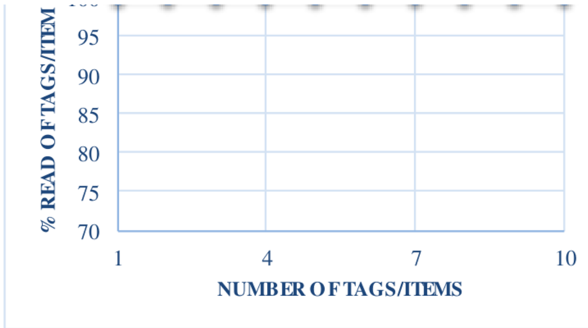

Figure 6. Experiments performed with RFID Tag Type-II

Figure 7. RFID Tag Type-III

We observed following results on performing experiments with RFID Tag Type-III as shown in Table 3 and Fig 5(b).

In the same fashion we experimented with RFID Tag Type-IV depicted in Fig 6(a).

We observed following results on performing experiments with RFID Tag Type-IV as shown in Table 4 and Fig 6(b).

In next stage we took combination of RFID tags. Initially we took combination of Tag Type-II and Tag Type-III with ten tags of each type. Results are shown in Table 5 and graph has been plotted in Fig. 11.

Similarly, we took combination of Tag Type-I and Tag Type-IV with ten tags of each type. Results are shown in Table 6 and graph has been plotted in Fig. 12.

Next we experimented with the combination of Tag Type-I, Tag Type-II and Tag Type-IV. Results are shown in Table 7 and Fig 13.

From the aforementioned experiments we observed that for up to eight items all the items were read accurately and completely irrespective of the type of the tag. As the number of items increased beyond

Table 3. Experiment Result with RFID Tag Type – III

No. of Tags	Average No. of Tags Read
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	9.8

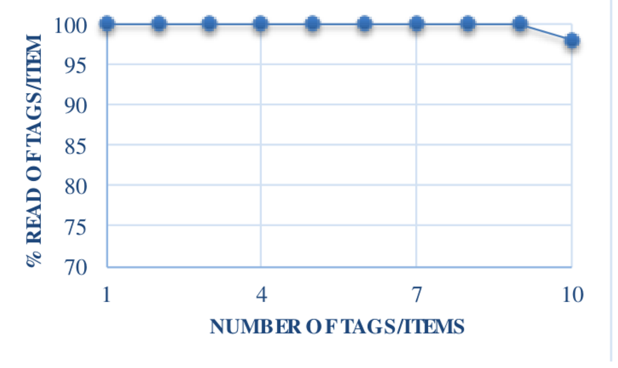

Figure 8. Experiments performed with RFID Tag Type-III

Figure 9. RFID Tag Type-IV

Table 4. Experiment Result with RFID Tag Type – IV

No. of Tags	Average No. of Tags Read
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	8.8
10	9.6

10	9.6

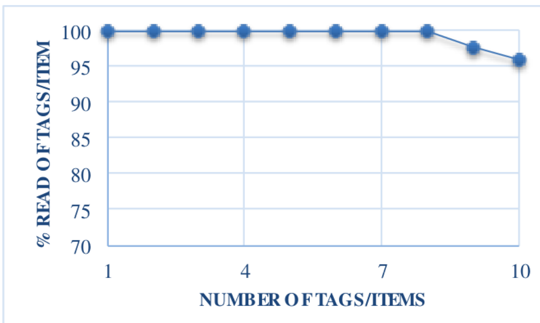

Figure 10. Experiments performed with RFID Tag Type-IV

Table 5. Experiment Result with Combination of RFID Tag Type – II and Type-III

No. of Tags	Average No. of Tags Read
2	2
4	4
5	6
8	8
10	10
12	11.8
14	13.6
16	15.4
18	17.2
20	19

eight, the percentage of items read decreased. Moreover, the readability also depended upon the type of the RFID tag. Average number of tags read for tags type I-IV is 9.4, 10, 9.8 and 9.6, respectively. When we take combination of type II and type III tags, out of 20 tags 19 tags can be read. Combination

20	19

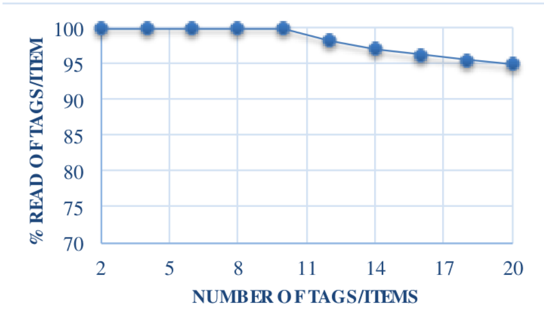

Figure 11. Experiments performed with the combination of RFID Tag Type-II and Type-III

Table 6. Experiment Result with Combination of RFID Tag Type – I and Type-IV

No. of Tags	Average No. of Tags Read
2	2
4	4
5	6
8	7.8
10	9.4
12	11.2
14	13
16	14.6
18	16.2
20	17.6

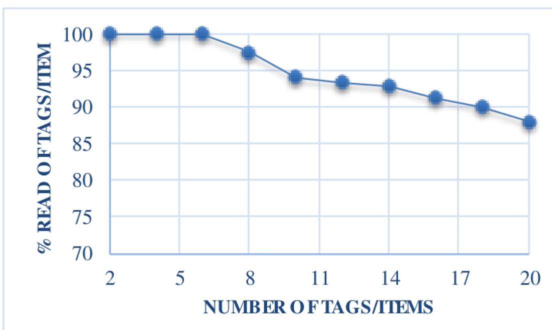

Figure 12. Experiments performed with the combination of RFID Tag Type-I and Type-IV

Table 7. Experiment Result with Combination of RFID Tag Type-I, Type-II and Type-III

No. of Tags	Average No. of Tags Read
3	3
6	6
9	8.8
12	11.6
15	14.4
18	17
21	19
24	21.2
27	23
30	24.8

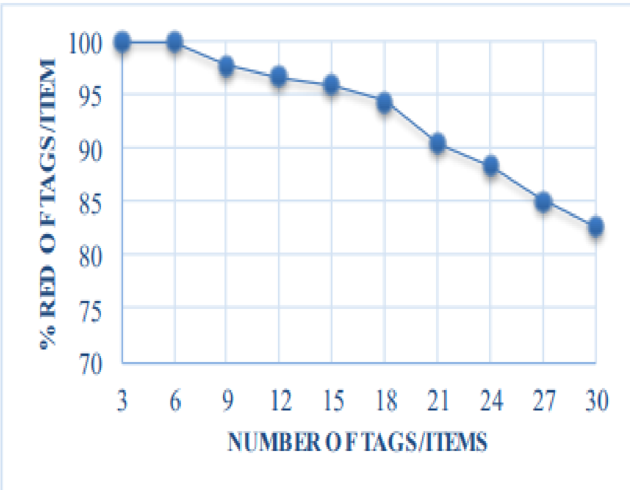

Figure 13. Experiments performed with the combination of RFID Tag Type-I, Type-II and Type-III.

of type I and type IV tags resulted in an average of 17.6 out of 20. In general, we can say the number of tags read after combination of any two types of tags is 18 out of 20. We have also experimented with 30 tags, 10 of each of type I, II and III, and experiment shows the numbers of tags read are 25 for different sets of experiments. The results vary depending upon the arrangement of the items also. Read percentage decreased when the items were clustered together. However, keeping the items loosely on the tray resulted in full readability. Moreover, for the Retail Store application, Type - II tag resulted in best readability when items are grouped together. The experiments show that in an Automated Retail Store it is advisable that RFID tags of only one type having the best readability should be used. Mix and match is to be avoided to ensure efficiency, accuracy and correctness of the system.

Figure 14. A tag attached with an Item in Future Retail Store

Conclusion

A scheme for Automated Retail Shop based on RFID is proposed in this paper. The RFID technology is one of the most promising technologies for identification and tracking purpose and it is an excellent option for deployment in enterprise applications like retail stores, supply chain management etc. Traditionally optical barcodes are used in the retail stores, however, they suffer from several drawbacks such as they are slow to read, require correct orientation towards the reader to be read and any damage makes them unreadable. Moreover using barcodes is a human-intensive activity at the Point of Sales (POS). Hence RFID technology is a better approach to overcome these shortcomings.

It has been observed that as the number of items at the Point of Sale increases, the percentage of items read is decreased. For different type of tags percentage read of tags is different. This restricts the number of items which can be passed through RFID gates in one go. It is advisable to choose the tags with best readability in the Store application. Moreover, combination of different types of tags should be avoided for best results. Further the items to be read should not be cluttered and clustered together for the sake of accuracy and correctness of the system. The use of RFID tags improves the efficiency and accuracy at the POS and further it also ensures security of the items as any unauthorized exit of the items may raise an alarm. The proposed scheme can be easily adopted in present day retail stores and shops with minor modifications in the existing infrastructure.

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