Location Filtering and Duplication Elimination for RFID Data Streams

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Abstract. For the past decade, Radio-Frequency Identification (RFID) technology has gained a significant momentum. It has promised to improve the efficiency of supply chain and library management by providing the automatic identification and data capture. It is expected that RFID will replace a barcode system in the near future. However, a large volume of data, resulting from the fast capturing RFID readers and huge number of tags, poses challenges for data management. Some of the captured data have errors such as data duplication or miss reads. Existing techniques are unable to eliminate RFID data duplication while correctly identifying the correct location of the tag. In this study, a location filtering and duplication elimination for RFID data streams based on set theory are proposed. Experimental results show that the proposed method has better quality of output data and at the same time provides the exact location of the tag.

1 Introduction

Radio-Frequency Identification (RFID) technology has gained significant momentum in the past few years. It has promised to improve the efficiency of business processes by providing the automatic identification and data capture. The core RFID technology is not new, and it can be traced back to World War II where it was used to distinguish between friendly and enemy aircrafts. Currently it is used for baggage and passenger tracking at the airports, in toll roads, smart box, security access, defense and military, postal package tracking, health care, library, etc [10], [11], [12], [14], [16], [19], [21].

However, captured data has significant percentage of errors particularly as a result of miss reads. To reduce the miss reads multiple readers can be applied, which can result in duplication of data. To eliminate duplication of data several techniques for filtering RFID data at the edge (before it gets stored into the database) have been proposed in the literature [6], [9], [17], [18]. However, these techniques only filter specific kind of errors generated by both reader and nearby environment. Therefore, a significant amount of wrong data is still recorded in database. The most common error is data duplication. These duplicated data can be eliminated but the question is which data should be kept and stored into the database to indicate the right location. To reduce a false negative reading

and to increase the accuracy of data it is recommended that at least two readers need to cover one area [20], which increases the probability that the tag will be recorded. However, if both readers capture the same tag it will result in data duplication and also will cause a location problem.

In this study we focus on the library scenario, where in line with recommendations [20] and to increase the data capture accuracy each bookshelf is covered by at least two readers. Because each tag is captured by multiple readers, which cover several shelves, tag must be allocated to the right location to the specific shelf where it is actually located. In this work, a Location Filtering and Duplication Elimination for RFID data streams are proposed. Our method ensures that the output data has better quality and at the same time ensures that the correct location of the tag can be identified. In experimental study we show that our method can provide the better quality of output data comparing to previously used methods.

The remainder of this paper is organized as follows. In section 2, some background information related to errors types and their causes is provided. In section 3, a location filtering methodology is introduced and in section 4 duplication elimination for RFID data streams algorithms have been proposed. In section 5, we present experimental results and finally in section 6 we provide an analysis and conclusion.

2 Background

RFID technology uses radio-frequency waves to automatically identify people or objects. RFID is automatic, fast and it is expected to replace the barcode system in the near future. The difference between RFID and barcodes is that RFID does not require a line-of-sight as long as it is within a range of the reader. RFID data, which is captured by the RFID reader, can be accumulated very fast and does not carry much information as it is raw. These data are not meaningful and are inaccurate. They need to be filtered before they get stored in database in order to reduce data volume and improve the quality of data.

RFID system is made of the following components:

- Tags (or Transponder) A microchip attached to an antenna that transmits and responds to radio signals of a particular frequency.
- Reader (Interrogator) Sends and receives RFID data to and from the tag.
- Middleware This layer pre-processes the RFID data and converts it into a meaningful representation [1], [4], [7].
- Application software Application specific component that resides on host computer.

2.1 Errors in RFID Data Streams

Due to the low-power and low-cost characteristics of RFID tags, reliability of RFID readings is of concern in many circumstances [8], [22].

There are four main types of errors in RFID data reading: unreliable readings, false negative readings (miss reads), false positive readings (noises), and redundancy readings (duplicate reads).

Unreliable readings: Individual sensor readings are often unreliable. For example, RFID readers tend to fail but continue to output faulty values. In an RFID deployment, environmental interference such as metal or water can sometimes cause unreliable readings. Moving tags (objects) is also a common issue that causes unreliable readings, for example, baggage with RFID tags in airports can move too fast on conveyor belts and might not get detected properly by the reader.

False negative readings: These problems are very common in RFID applications and often happen in a situation of low-cost and low-power hardware, which result in frequently dropped reading [13]. False negative readings usually happen when multiple tags are to be detected and Radio Frequency collisions occur and signals interfere with each other, preventing the reader from correctly identifying tags [6].

False positive readings: False positive readings mean when additional unexpected readings are generated. This can be caused by the RFID tag outside the normal reading scope of a reader, captured by the reader or unknown reasons from the reader or environment [6].

Redundancy readings: As stated in [13], the redundancy problem is recognized as a serious issue in RFID and sensor networks. Redundancy can happen at two different levels, redundancy at reader level and redundancy at data level:

- Redundancy at reader level occurred when there are more than one reader deployed to cover a specific location.
- Redundancy at data level occurred as data streams. The RFID data can be captured very fast several times. Because raw level of RFID data does not have a meaningful information same tags can be captured more than once therefore it is necessary to identify and eliminate those data before they get stored in database.

2.2 Related Works

Several method related to the RFID data duplication elimination has been presented in the literature:

- In [6], two algorithms for duplication elimination have been proposed, baseline merge and hash merge. However, these algorithm do not consider location filtering, they consider that all data streams are from the same reader (location).
- In [17], [18], duplication elimination technique called Arbitrate stage has been introduced. This stage belongs to Extensible Sensor stream Processing (ESP), which can only eliminate duplicate tags under certain circumstances. In experiments, the redundant reader is known and any repeated tags from that reader are recognize as duplication.

- In [9], an algorithm called Redundant Reader Elimination (RRE) has been proposed, which is a randomized, decentralized, and localized approximation algorithm for the redundant reader elimination problem. This technique will disable some redundant reader when the other reader is activated. All data will be read from one reader at the time, which means that any Electronic Product Code (EPC) read by this reader will have redundancy only in instances when EPC tags stay in the time frame too long and get captured more than once. This duplication can be easily removed and there will be no need to allocate these EPC to different location since it was read from the same reader.

3 Location Filter and Duplication Elimination -Methodology

Our methodology uses the set theory in order to solve a location and data duplication problems. Firstly, a sample library scenario is set up where there are several bookshelves, books and readers. It is assumed that there will be at least two but no more than three readers to cover one bookshelf. If only one reader per shelf is deployed and if this reader fails to read some EPC tags from that shelf, the result will have a false negative error.

In Figure 1, running scenario is shown where there are four bookshelves covered by five readers. As displayed, bookshelf 1 laid within the intersection of reader 1 and reader 2. In line with recommendation in the literature, this setup is overly favorable to the RFID technology since at least two readers are needed to cover one shelf in order to minimize reading error rates.



Fig. 1. An example of Library Scenario. The coverage area of each shelf is an intersection of two readers. There are four shelves, five readers, and the range of the reader is 1 meter in radius.

The methodology for location filtering is derived from a naive set theory in which a set is described as a well-defined collection of objects. These objects are called the elements or members of the set. Objects can be anything such as numbers, people, other sets, etc. We first make the assumption that, no tags outside the reader range can be captured. However, reader failure is unavoidable and should be handled once it occurred. There are four rules:

- 1. No reader failure,
- 2. One reader failure,
- 3. Two readers failure,
- 4. Three readers failure

We will only implement these rules to handle up to three readers failure since we assume that out of five readers, there should not be more than half failure in readers. However, in reality, more readers may fail at the same time, which is beyond the capability of this scenario. If higher number of readers that fail at the same time need to be considered, a higher number of readers per shelf should be implemented and same logic as presented in this work need to be followed.

3.1 Rule One: No reader failure

The first rule applies to the case where none of the five readers from Figure 1 had failed. The intersection of two readers where a specific shelf lays can be represented as in equation 1.

$$A \cap B: = (x : (x \in A) \land (x \in B)) = (x \in A : x \in B) = (x \in B : x \in A)$$
(1)

Where: \in = Belong to, \cap = Intersect.

Equation 1 shows that, where Both $x \in A$ and $x \in B$, then A and B are intersected. For the area of the intersection between the two readers, reader A and reader B, a bookshelf will be placed within this area to ensure that all tags attached to each book will be captured by both readers. This area of intersection where the bookshelf lays can be represented as in equation 2 where *ReaderA* count as one set and *ReaderB* count as another set.

$$ShelfS = ReaderA \cap ReaderB$$
 (2)

For example, S1 is covered by R1 and R2, therefore any tags captured by both R1 and R2 belong to S1.

3.2 Rule Two: One reader failure

There are five possibilities that one reader may failed. For example, R1 may failed while other readers remain function. Therefore, R1, R2, R3, R4, and R5 may failed but not at the same time.

The intersection area of two readers can be used to identify the right shelf where a specific EPC tag belong to, even though there is a failure in some readers. For example, if R2 in Figure 1 failed, we are still able to identify which tags belong to S2 using a relative complement of A and B as shown in Equation 3.

$$A \neg \in B: = (x: (x \in A) \land \neg (x \in B)) = (x \in A: \neg x \in B) \quad (3)$$

Equation 3 shows that where $x \in A$ but not $x \in B$, then A does not belong to B.

Equation 4 shows that ShelfS is the shelf where reader had failed to capture any data. ReaderC is one reader to the left, if the failed reader is on the left of ShelfS; or ReaderC is one reader to the right, if the failed reader is on the right of ShelfS. ReaderD is two readers to the left, if the failed reader is on the left of ShelfS; or two readers to the right, if the failed reader is on the left of ShelfS; or two readers to the right, if the failed reader is on the left of ShelfS; or two readers to the right, if the failed reader is on the right of ShelfS.

$$ShelfS = ReaderC \neg \in ReaderD$$
 (4)

By using Equation 4, we can identify EPC data that belong to S^2 by eliminating those data within the intersection between R^3 and R^4 . This can be represented as:

$$S2 = R3 \neg \in R4$$

When R2 fails and we need to know which data belong to S2, we need both data from R3 and R4 (*ReaderC* = R3, *ReaderD* = R4) since S2 is on the right side of R2. We already know that the intersection between R3 and R4 is where S3 stands, therefore, any data that are not within this intersection belongs to S2.

In the case that only one reader exist to the left or to the right of the failed reader, we will know for certain that tags captured by that reader belong to one shelf. For example, R2 failed and we need to know which EPC belong to S1. Since there is only one reader to the left, we know that EPC captured by this reader (R1) belong to S1.

No matter which reader fails, Equation 4 will still be able to allocate tags to their right location.

3.3 Rule Three: Two readers failure

In Table 1 we show all ten possibilities when two readers may fail. However, out of these ten, we only focus on six possibilities, where two readers that fail are not subsequent to each other. For example, we will not implemented algorithm to handle the case of R1 and R2 failure together. This is because if two subsequent readers failed at the same time, EPC data from S1 will not be captured at all. As mentioned earlier if there is a need to cover scenario where two readers that cover the same shelf fails, then there is a need to implement a higher number of readers per shelf. In case of two subsequent readers failure the percentage of successful allocation of tags to S1 is equal to zero, and therefore, it is unnecessary to consider those cases. Thus, options No. 1, 5, 8, 10 from the Table 1 will not be considered.

Possibility	$\mathbf{R1}$	$\mathbf{R2}$	$\mathbf{R3}$	$\mathbf{R4}$	$\mathbf{R5}$
1	Х	Х			
2	Х		X		
3	Х			X	
4	Х				Х
5		Х	X		
6		Х		X	
7		Х			Х
8			X	X	
9			X		Х
10				Х	Х

 Table 1. Ten possibilities of two readers failure at the same time. "X" represents a failed reader.

The intersection area of two readers can be used to identify in which shelf the specific EPC tag belong, even though there is a failure in some readers. This rule was represented earlier in Equation 4. However, this equation cannot handled the case when two readers separated by one reader in the middle, failed at the same time. For example, it is impossible to tell if the EPC data belong to either S1 or S2 if R1 and R3 failed together. In order to handled this situation, we use a randomization function to allocate the specific EPC data to either S1 or S2. In Table 1 we can see that the possibility that falls to the above mentioned case are options number 2, 6, and 8.

$$Shelf A^{c}: = (x \in Reader E : x \neg \in Shelf A)$$

$$(5)$$

Where: c = Complement.

Equation 5 shows a complement of ShelfA (in ReaderE) where $ShelfA^c$ is a set of all members of ReaderE, which are not members of ShelfA.

$$ShelfB = ShelfA^c \tag{6}$$

Where: ShelfB is a set of all members of ReaderE, which are not members of ShelfA.

Equation 6 can be used to allocate tags randomly, to either *ShelfA* or *ShlefB*, using data from *ReaderE*. For example, R1 and R3 has failed to capture any tags. The only active reader, which covers S1 and S2 is R2. Therefore, by using Equation 6, *ShelfA* is S1, *ShelfB* is S2 and any data from R2, that do not belong to *ShelfA*, belong to *ShelfB*.

The reason for using Equation 6 to randomly allocate tags to two different locations is because; if in this case we only allocate all data from *ReaderE* to *ShelfA*, *ShelfB* will be empty. In the real world deployment, if tag from *ReaderE* get allocated to the wrong location, we can easily reallocate these tags to their correct location by searching through two shelves, one to the left and one to the right of their current location.

3.4 Rule Four: Three readers failure

There are ten possibilities that three readers may fail, in Table 2 we shows all ten possibilities. However, out of these ten combinations, we only focus on options where three failures are not subsequent to each other. As mentioned in the previous rule, we will not implement any algorithm to handle the case of R1, R2 and R3 or R1, R2 and R4 failed together. This is because, if the two or three readers next to each other failed at the same time, EPC from S1 and/or S2 will not be captured by any reader. The percentage to allocate tags successfully to S1 and/or S2 is equal to zero, therefore, it is unnecessary to handle that case. Thus, possibility number 1-4 and 6-10 from the Table 2 will not be considered.

Table 2. Ten possibilities of three readers failure at the same time. "X" represents afailed reader.

Possibility	$\mathbf{R1}$	$\mathbf{R2}$	R3	$\mathbf{R4}$	$\mathbf{R5}$
1	Х	Х	Х		
2	Х	Х		X	
3	Х	Х			Х
4	Х		Х	X	
5	Х		Х		Х
6	Х			Х	Х
7		Х	Х	X	
8		Х	Х		Х
9		Х		X	Х
10			Х	Х	Х

For possibility number 5 from shown in Table 2, it is certain that this case can be handled by using Equation 6. However, this equation is required to be applied twice: at first, it must be applied to S1 and S2 and then, it must be applied to S3 and S4.

4 Location Filter and Duplication Elimination -Algorithms

Following algorithms are based on the methodology presented in the previous section where we described how to allocate EPC data to their right location.

The first algorithm is *Intersection Algorithm*, which compares EPC data between two readers. If the same data exists in both readers, this specific data will be allocated to the specific shelf. The algorithm is bases on Equation 2. For example, R1 and R2 both has ten EPC as their members. By using the *Intersection Algorithm*, each member of R1 will be compared to each members of R2. If the member of R1 matched one of the member of R2, this member will be allocated to the S1.

Algorithm I Intersection Algorithm	
Input: Reader A, Reader B	
Output: Shelf S	
begin	
for (Every member of Reader A) do	
for (Every member of Reader B) do	
if (Reader $A = Reader B$) then	
Put member of Reader A into Shelf S	
end if	
end for	
end for	
end	

The second algorithm is *Relative Complement Algorithm*, which also compares EPC data between two readers. However, if there are duplications between both readers, these data will be ignored. Any data without duplication will be allocated to the specific shelf. The algorithm is based on Equation 4. For example, R3 and R4 both has ten EPC as their members. By using the *Relative Complement Algorithm*, each member of R3 will be compared to each members of R4. If the member of R3 matched one of the member of R4, this member will be discarded. The rest of EPC within R3 will be allocated to the S2.

Algorithm 2 Relative Complement Algorithm
Input: Reader C, Reader D
Output: Shelf S
begin
for (Every member of Reader C) do
for (Every member of Reader D) do
if (Reader C $:=$ Reader D) then
Put member of Reader C into Shelf S
end if
end for
end for
end

Finally, the last algorithm is *Randomization Algorithm*. This algorithm will randomize values between "0" and "1". If the outcome is equal to "0", the specific EPC data will be allocated to the shelf *SA*. Otherwise, if the outcome is equal to "1", the EPC data will be allocated to the shelf *SB*. A *Randomization Algorithm* is based on Equation 6. For example, R_4 has ten EPC as its members. By using the *Randomization Algorithm*, each member of R_4 are randomly allocated to the S_3 or S_4 . In this instance, five EPC are allocated to the S_3 and the other five EPC are allocated to the S_4 . However, in the real randomization, there may not be equal number of tags allocated between two shelves.

Algorithm 3 Randomization Algorithm

```
Input: Reader E

Output: Shelf SA, Shelf SB

begin

for (Every member of Reader E) do

Randomize number between 0 AND 1

if (Reader E = 0) then

Put member of Reader E into Shelf SA

else

if (Reader E = 1) then

Put member of Reader E into Shelf SB

end if

end for

end
```

By using these three algorithms, any duplication that exists between two readers can be automatically eliminated, since only one EPC from two readers will be allocated to the specific shelf.

5 Experimental Evaluation

To show the practical relevance of our method of duplication elimination and location filtering extensive experimental evaluations has been conducted.

5.1 Environment

The experimental setup is shown in Figure 1. It is considered that there is well controlled environment where there is no metal or water nearby. Five 915 MHz RFID readers (Alien ALR-9780) from Alien Technology [3] are used and allocated opposite to bookshelves with their middle point of sensors between two bookshelves. Four bookshelves are allocated 20cm apart from each other facing their readers. Each shelf is stocked with books represented with Alien (ALL-9250) passive tags [2]. Tags are positioned in the same plane as readers oriented such that their antennaes were directly facing readers. Note that this setup is overly favorable to RFID technology as it attempts to alleviate many of the known causes of degraded readings [15].

Algorithms proposed in section 4 are developed in Netbeans 4.1 and built in as a extension to the Sun Java RFID software [5].

5.2 Data Set

For both experiments, the EPC data are simulated according to the intersection of two readers. For example, R2 will have both data from S1 and S2 while R1 will only have data from S1. In experiment one, the correct percentage

of successful tags allocation will be compared versus the size of the data set. In experiment two, the correct percentage of successful tags allocation will be compared between twelve possibilities of reader/readers failure. We will also compare the results of *Location Filtering* and *Duplication Elimination* approach to the traditional previously used naive approach as explained in subsection 2.2 where one reader covers only one bookshelf.

Experiment One

For the first experiment, four data sets of 10EPC, 25EPC, 50EPC, and 100EPC per bookshelf are simulated. The EPC data are in standard format (their type, size and identification). As explained earlier in chosen scenario there is five readers. Each bookshelf will be covered by two readers, for example, R2will cover data from S1 and S2, while R3 will cover data from S2 and S3 etc. For this experiment, there is no failure in data capturing progress. It is assumed that all data for each shelf are captured by both readers. In order to eliminate effect of miss reads smoothing algorithm, which is part of the Sun Java RFID software was used. All captured data represent smoothing of five reads to ensure that no miss read occurs. The expected results from this experiment is that all EPC data captured by R1 to R5 will be allocated correctly into their right location.

Experiment Two

For the second experiment, the efficiency of the algorithm will be tested by disabling some readers and assuming that these readers have failed during the experiment. The data set will be similar to experiment one except that there will be no data for the disabled readers. For example, R2 failed to read any data, which means that any EPC data from S1 and S2 will only get captured by R1 and R3. In this experiment, there are some readers' failures in data capturing progress. It is assumed that at least one reader will always capture all data and according to the assumption that two readers, which cover the same area, will not fail at the same time as explained in subsection 3.3. The challenge will be to locate tags captured by one reader (no intersection found) to their right location. The expected results from this experiment is that all EPC data from all possibilities, where no subsequent reader or two readers from left and right of active reader failed at the same time, will be allocated to their right location. Table 3 shows twelve possibilities of interest for this study of readers' failures

In Table 3, possibility 0 has no reader failure, possibilities 1-5 has one reader failure, possibilities 6-11 has two readers failure and possibility 12 has three readers failure.

5.3 Required Algorithms

In the first experiment, we assume that there is no reader failure during the process, therefore the only algorithm needed for this situation is *Intersection Algorithm*, where all tags from every bookshelf can be allocated using intersection rule.

In the experiment two, twelve possibilities of reader failure are shown in Table 3. In the case of one or two readers failure at the same time, but no two

Possibility	$\mathbf{R1}$	$\mathbf{R2}$	$\mathbf{R3}$	$\mathbf{R4}$	$\mathbf{R5}$
0					
1	Х				
2		Х			
3			X		
4				X	
5					X
6	Х		Х		
7	Х			X	
8	Х				Х
9		Х		X	
10		Х			X
11			X		X
12	Х		Х		Х

Table 3. Possibilities of none, one, two or three readers failure at the same time. "X"represents a failed reader.

readers on the left and right of active reader failed together, we need a *Relative* Complement Algorithm. For example, R1 and R4 fail to captured any data but R2 and R3 are still active at that time, by using a relative complement rule, we are still able to allocate all tags to their right location. However, in the case when two readers on the left and right of one active reader have failed, we need a *Randomization Algorithm*. For example, R1 and R3 fail to capture any data and only R2 remains active at that time, but using a *Randomization Algorithm*, it is still possible to allocate some tags to their right shelf correctly.

Experiment One: No reader failed = *Intersection Algorithm*

Experiment Two:

R1 or R2 or R3 or R4 or R5 or R1 & R4 or R1 & R5 or R2 & R5 failed = Intersection Algorithm and Relative Complement Algorithm

R1 & R3 or R2 & R4 or R3 & R5 failed = Intersection Algorithm, Relative Complement Algorithm and Randomization Algorithm

R1 & R3 & R5 failed = Randomization Algorithm

5.4 Results and Analysis

For experiment one, we will not show the results comparison graph due to space limitation because results show that there are no differences caused by the size of data set and the allocation of all tags are 100 percent correct. The reason that the size of data set does not affect the result is because, the *Intersection Algorithm* does not rely on the size of data set, but only rely on the accuracy of readers and data captured from them.

Results for experiment two for all twelve possibilities of reader/readers failure is presented in Figure 2. The Figure 2 shows that the percentage of success of possibilities from Table 3 number 1, 2, 3, 4, 5, 7, 8, and 10 are 100 percent. This proves that the *Intersection Algorithm* along with *Relative Complement* Algorithm has successfully allocated all tags to their right shelf. However, possibilities number 6, 9, 11, and 12 has not achieved 100 percent allocation. This is because, it is required to use a *Randomization Algorithm* to randomize tags from one reader to two shelf within its range. Possibilities number 6, 9 and 11, have only about 70 percent success in the allocation. This is because a *Randomization Algorithm* need to be applied to two out of the four shelves. Therefore, two shelves has achieved 100 percent allocation, while the other two shelves has achieved around 50 percent allocation each. This gives the overall percentage of about 70 percent depending on randomization. On the other hand, possibility number 12 from Table 3 has the lowest percentage of success of about 50 percent, this is because three of five readers failed to captured tags, and all data that are captured need to be randomly allocated to all four bookshelves.



Fig. 2. A result of experiment two, where percentage of success is shown versus four different size of data set.

Figure 3 displays a comparison between the percentage of success of *Location Filtering* and *Duplication Elimination* approach versus the naive approach, where one reader cover only one bookshelf. We only present results for data set of 25EPC, since the size of data set does not affect the qualitative results.

Considering the possibility number 0 from Table 3 when no reader fails, both approaches performed evenly. For possibility number 1 to 5, where only one reader fails, we can see that only possibility number 5 of the naive approach performed evenly to our approach. This is because in the naive approach, only four readers are needed to cover four shelves. Reader five however, is not necessary, and the failure of it will not affect the quality of data. For possibility number 6 to 12, where two and three readers has failed, the performance of both approaches degrade for some possibilities. However, *Location Filtering* and *Duplication Elimination* approach still outperforms the naive approach.



Fig. 3. A comparison between the percentage of success of Location Filtering and Duplication Elimination approach vs. Naive approach. For all possibilities, a data set of 25EPC is used.

6 Conclusion

In this study, we identified the significance of RFID data allocation and duplication elimination and developed efficient method to eliminate duplication and at the same time to ensure that the RFID tags can be allocated to their correct location. Specially, for location filtering, we proposed three algorithms using set theory rules to decide which location the specific tag belong to.

In experimental evaluation we showed that our method ensures identification of correct locations even in case of reader failures and more importantly ensures that the RFID tags can be read regardless of some reader failure, which means no miss reads will happen.

Our approach of location filtering and duplication elimination is essential to provide correct RFID data to their right location before they can be further processed, transformed, and integrated for RFID-enabled applications.

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