High-speed Collective Readout of Large Quantities of Moving Electronic Tags using the Response Probability Control Method

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***Abstract*—When more than two electronic tags respond to a reader request, the request fails. This is referred to as the collision problem. To overcome this problem, a novel electronic tag readout method, termed the response probability control method (RPCM), is proposed in this paper. In the RPCM, the reader indicates the response probability of a request, ensuring rapid and simultaneous readout of multiple electronic tags. We have already reported the basic RPCM characteristics for a large number of non-moving electronic tags. In this study, the extended characteristics of electronic tags located on a conveyor belt are simulated, and a portion of them is analyzed. The RPCM and the existing dynamic framed slotted ALOHA (DFSA) method are compared. The simulation demonstrated that, in the case of non-moving electronic tags, the readout of the RPCM is 1.6 times faster than that of DFSA, while in the case of moving electronic tags, it is more than 2.5 times faster.**

***Index Terms*—electronic tag, radio frequency identification (RFID), collision avoidance, FSA, DFSA, collective readout.**

I. Introduction

AN ELECTRONIC TAG or radio frequency identification (RFID) [1] (Hereafter we simply call it a tag) contains a chip with an identifier and attribute information that can be read without using wires, rather by using a small antenna on the chip. Tags can store a large amount of data compared to barcodes, to the extent that they can store identification data and attributes pertaining to individual products. It is possible to perform flexible operations since it is only necessary for the tags to be close to the reader in order for the data to be read. Many applications and a wide range of uses [2] are expected provided security and privacy issues can be overcome [3]. In addition, the range of applications is expected to expand greatly if large quantities of moving tags can be read collectively at high speeds.

However, in order to read multiple tags simultaneously, it is important to avoid collision problems when multiple tags respond simultaneously to a readout request from a reader. The currently existing collision avoidance methods are framed slotted ALOHA (FSA) [4], and dynamic framed slotted ALOHA (DFSA) [5] which is an improved version of FSA. In both of these methods, multiple tags are readout consecutively in response to a single readout request.

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The response probability control method (RPCM) [6] proposed in this paper uses a request command for every tag readout. Using this method, the readout speed was about 1.6 times faster than the DFSA method for non-moving tags (hereafter referred to as a stationary system) [6]. This paper examines the readout of tags that are moving (hereafter referred to as a moving system). Simulation results obtained showed that the readout speed could be increased more than 2.5 times compared to DFSA by improving the way readouts are performed.

The performance of this collision avoidance method is evaluated under physically ideal coditions. Verification of these physical conditions through implementation is for further study.

The reamining of this report is organized as follows. We introduce the overview of tag readout technology in Section 2. Section 3 provides our proposed method RPCM. Then, we give the results of simulation experiments in Section 4 and compare RPCM with DFSA in Section 5. Finally, Section 6 describe the conclusions and future works.

II. Electronic Tag Readout Technology

Tag readout methods can be broadly divided into two categories. Single readouts may be performed, in which one tag is read at a time, or readouts may be done collectively, in which multiple tags are read simultaneously. In this paper, collective readout methods are investigated.

A. Existing Electronic Tag Readout Technology

A tag can be viewed as a single technological component, combining a small antenna with an integrated circuit. From another viewpoint, the technology can be considered as a system composed of tags and a reader. The first topic that will be examined as a system is the problem of mutual interference when there are other readers in close proximity [7]–[10]. The second topic that will be addressed is a method for speeding up the readout of tags [11], while the third topic is avoiding collisions between the responses of multiple tags.

There are two kinds of methods for avoiding collisions, namely a deterministic method and a statistical method. The deterministic method reduces the number of tags to be read to a single tag by a process specifying the identifier [12]–[15]. While this method is effective when searching for tags from among an extremely large number of tags, it is not appropriate for the collective readout of a large number of tags together, since it requires too long to narrow the focus.

The statistical method repeats the probabilistically successful readouts until the final tag is read. FSA [4], based on the wireless packet telecommunication architecture (ALOHA) [16], is widely used for this method, while the improved DFSA has been proposed [5]. In the statistical method, the reader determines the number of slots for succeeding readouts based on the estimated number of pre-readout tags. There are several studies on how the accuracy and speed of estimation affect the effectiveness of read-out [17]–[20].

B. Standardizing the Electronic Tag Readout Method

We can list three standards applicable to tag readouts: the ISO/IEC 14443 series [21] with a maximum distance between card and reader of 7-15 cm, and the ISO/IEC 15693 series [22] with a maximum distance of 50-70 cm, the ISO/IEC 18000-6C (EPCglobal Class 1 generation 2) [18] with a maximum distance of a few meters.

C. Overview of FSA and DFSA

Both FSA and DFSA are mainly equal to Slotted ALOHA except for the concept of frame. A certain amount of multiple slots (referred to as frame sizes) are concatenated into a single frame, and this frame size is attached to a frame readout request from the reader. The tags always return a response by using one of slots inside one frame. In FSA, a fixed pre-determined frame size is selected for every frame readout request (e.g., 16 or 64), whereas DFSA has expanded functionality allowing the selection of arbitrary frame sizes.

The readout fails for any slot if there is no response from tags or if there are multiple responses; it succeeds when there is a single response. The highest readout success probability is attained when the frame size is made to correspond to the number of pre-readout tags [5].

The maximum success probability converges to $1/e$, where e is the base of the natural logarithm (2.718), when there are a sufficiently large number of pre-readout tags.

Similar to RPCM, the number of pre-readout tags is estimated, and response probability of tags is controlled through frame size. As mentioned later, advantage of RPCM is readout speed brought by quick estimation of pre-readout tag number.

In the FSA and DFSA methods, the responses from tags that have already been successfully registered may be suppressed [5] or not suppressed [4]. The sequence is simple when they are not suppressed, but there are responses over multiple frames from tags that have already been readout, and this increases the readout complete time. If the responses are suppressed from those tags that have already been successfully registered, then unnecessary readouts do not occur, but a readout suppress request must be made between frames. This paper shows a comparison between response suppressed DFSA and RPCM.

In case of large number of stationary tags, optimum readout time for a tag is given below.

$$\overline{t_{read}^{DFSAopt}} = t_{slot}e + t_{sup} \tag{1}$$

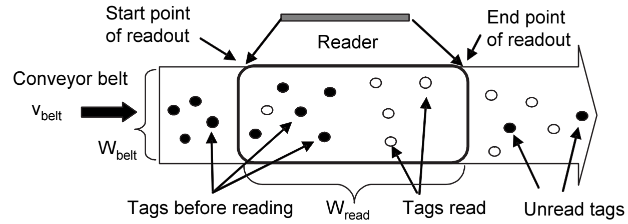

Fig. 1. Readout of tags on a conveyor belt

Where, t_{slot} is one slot time, t_{sup} is suppress sequence time for one tag. The bar indicates the observed average (expectation). The bar notation is also used below.

III. Readout of Electronic Tags by RPCM

Figure 1 shows the readout conditions of tags on a conveyor belt. The movement speed is fixed for readout of tags on the belt, and thus the relative distance between tags never changes. Product management and material flow control, etc. are also candidates for this application, where a moving reader is capable of reading non-moving tags.

A uniform random distribution is assumed for the tags on the conveyor belt. Since this assumption was made to investigate the basic performance characteristics of the readout in moving systems, it will need to be verified in future. In addition, the following conditions were employed in the examination.

- Service Conditions
  - The number of tags to be read collectively varies, and that number is never specified in advance.
  - While stationary systems are evaluated in terms of increases in the reading speed, moving systems are evaluated based on the number of tags that remain unread at the end point of readout.
- Physical Conditions
  - A tag cannot detect signal that other tags send.
  - The mutual coupling effect between tags is not considered. [1]
  - The capture effect is not considered. [2]
  - Interference from other readers is not considered.

A. RPCM Sequence and Movement

Figure 2 shows the RPCM sequence.

1) The reader sends an identifier readout request (referred to as the readout request) to tags. Using that operand, the reader specifies the probability that the tag should respond to the request (referred to as the response probability).
2) If neither of the tags responds (referred to as a readout response), the reader detects a readout timeout, and the readout fails.

[1] When electrical power is applied to a tag, it reduces the electrical load of nearby tags, making them difficult to read.

[2] When multiple electrical wave signals are received having different electrical strengths, the weaker signal is completely suppressed, while the stronger signal is received normally.

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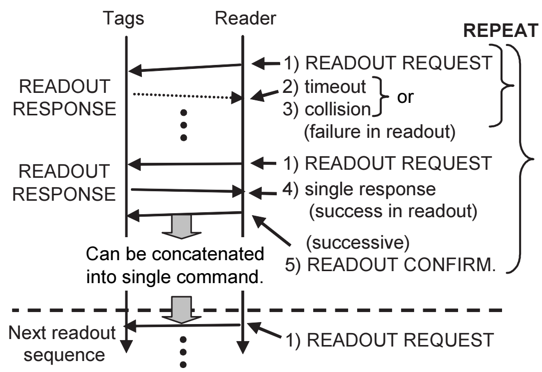

Fig. 2. Readout of tags by Response Probability Control Method (RPCM)

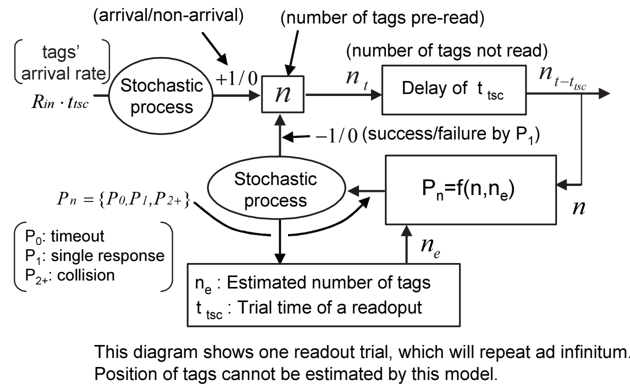

Fig. 3. Readout process of RPCM

3) If two and more tags respond, the reader detects a response collision, and the readout fails.
4) If a single tag responds, the reader successfully receives its response.
5) The reader issues confirmation that provides notification that reception has been successful (referred to as the readout confirmation). Readout confirmation is performed using the 1 bit coming from the subsequent readout request. Thus, we assume that this time is zero in the following analysis.

The readout request 1) is repeated after steps 2), 3) or 5), and the tags attach an error detection code to the response. The reader examines this error detection code, and if it is received normally, then there is no collision. If it is not received normally, then it is determined that a collision had occurred.

A tag, having received readout confirmation, detects successful identifier registration, and do not respond to future readout requests.

B. Process Model

Figure 3 shows the RPCM process model. This is used to analyze the characteristics in the case of reading moving tags. Note that this model cannot be used for the analysis of Probability Response Compensation Method (Sec. III-F) in which the readout position affects the system performance. The timeout time, single-response time, and collision time for the reader are assigned as t_{out}, t_{suc}, and t_{col}, respectively. These time values also include the necessary request command time and the internal processing time, which are collectively expressed as t_{tsc}.

Suppose that tags arrives at the readout area on the conveyor belt according to a Poisson distribution with an average arrival rate of R_{in}. For a minute t, the probability of arriving a tag at the interval of t becomes $R_{in}t$. For simplifying calculation, we use t_{tsc} instead of t. Although we can also derive the probability that two or more tags arrive at the interval t_{tsc}, the probability can be negligible. In what follows, we show the process illustrated in Fig. 3.

1) Derive the condition whether a new tag arrives (*arrival*) or not (*non-arrival*) as a stochastic process for every t_{tsc}.
2) Update the number of pre-readout tags at t (*number of tags pre-read*) based on the condition.
3) Calculate probabilities P_0, P_1, and P_{2+} by substituting $n_{t-t_{tsc}}$ and n_e to Eqs. (2), (3), and (4), respectively.
4) Derive the readout result (no response, single response, or collision) from P_0, P_1, and P_{2+} as a stochastic process for every t_{tsc}.
5) Update *number of tags pre-read* according to the readout result.
6) Renew n_e using the method estimating the number of pre-readout tags (detail of the method is described later).
7) Set t_{tsc} to t_{out} if the readout result was no response and t_{col} otherwise. Go back to Step 1 after substituting n_t to $n_{t-t_{tsc}}$.

Since we have not obtained the general solution of this model due to its complexity, we give numerical results in what follows. Figure 4 shows the relationship between the number of pre-readouts and the readout success probabilities. When the number of pre-readouts is in the vicinity of one or less, multiple timeout occur during a single successful readout. In this case, a success probability having a pre-readout number of 1 should directly connect the origin (0,0) by a straight line. But, if the estimated number is fixed to a large number compared to 1, the P_1 formula is used for the sake of simplicity.

As Fig. 4 shows, when the number of pre-readouts is correctly estimated, readout success probability increases remarkably in the region where the number of pre-readouts is small. But, when there is a rapid increase of arrivals in this area, 1) the estimated error increases; 2) the success probability decreases; 3) the number of pre-readouts increases; and these effects repeat so that readout sometimes terminates completely. In order to prevent this situation from occurring, a minimum value must be set for the estimated number.

There is a possibility of pre-readout-number divergence when the estimated number is fixed. When estimating the number of pre-readouts, the estimated value is automatically adjusted and the possibility of such divergence decreases.

The readout conditions determined by each probability conclude the estimated number of pre-readouts as follows. When there is no response, the estimated number of pre-readouts is multiplied by the factor of decrease (*dfactor*); and

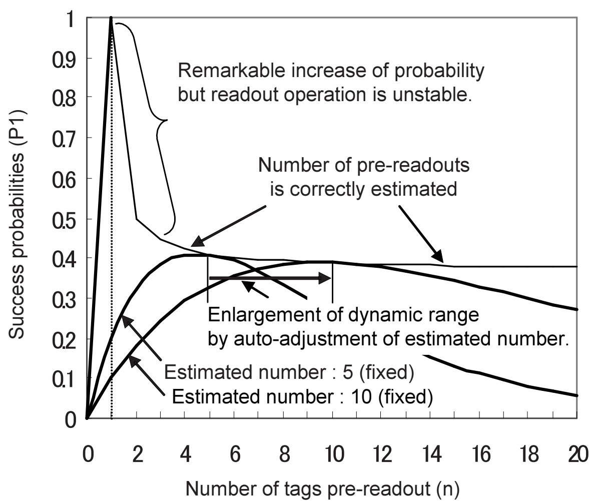

Fig. 4. Number of tags pre-readout and various success probabilities

when there is a collision, it is multiplied by the factor of increase (*ifactor*). In Ref [6], the optimal relationship between these factors is derived. When there is a single response in a stationary system, the estimated number of pre-readouts is subtracted by the number of readouts; however in a moving system, it is not substracted by any number since it balances with the number of arrivals (detail of the subtraction process is described later).

There are multiple methods to estimate the number of pre-readout tags [18]–[20]. Each of them is a synchronous method based on slotted ALOHA while RPCM is an asynchronous one. We believe that such an asynchronous method is more useful in the moving system in terms of the following reasons. 1) The reader can skip to the next readout without waiting a slot finished if no response occurs. 2) The reader can send a readout confirmation to its corresponding tag using one bit in a successive readout command (see Fig. 2). 3) The reader can quickly adapt to the change in the number of pre-readout tags.

In what follows, we compare RPCM with other existing methods.

- Slot-count algorithm of EPCgloval Class 1 Generation 2 [18]
  At a reader (called interrogator in Ref. [18]), a frame size is expressed by 2^Q where Q is an integer with the maximum value of 16. Each tag has 16 bit memory, named Q bit. At the start of each frame, it writes a random number to Q bit. Then, it subtracts the stored number by one at the end of each slot. If the stored number becomes zero, it sends the response to the reader. Thus, Q bit performs random slot selection function. The readout efficiency is optimized when 2^Q is set to the number of pre-readout tags. They have also given an estimation method of the number of the pre-readout tags: The reader multiplies or divides the estimated number by 2^β depending on readout states. Like RPCM [6], an optimal relationship between increase factor and decrease factor should be derived to improve the readout efficiency.
- Enhanced Dynamic Framed Slotted ALOHA [19]
  When the estimated number of pre-readout tags exceeds the maximum frame size, the reader divides the pre-readout tags into several groups whose frame size is not greater than the maximum. The reader controls that only one group responds to its readout request. They have shown that the performance can be improved 85-100% compared with the original DFSA under a system with a large number of tags. On the contrary, RPCM does not require such a grouping mechanism because it can stably perform even in a system with a large number of pre-readout tags.
- Bayesian slot-by-slot updating [20]
  At every slot, the reader estimates the number of pre-readout tags based on Bayes' theorem by substituting conditional distribution probabilities of tags that were obtained from the observed readout results (i.e. the number of timeouts, single response, and collisions). If the optimal frame size does not change, it keeps reading. Otherwise, it restart reading with an appropriate frame size. Although this method can quickly adapt to the change in the number of pre-readout tags, it cannot skip a non-response slot to keep the synchronization among tags.

C. Analysis and Simulation of RPCM Stationary System [6]

Important formulas for stationary systems are given below.

$$P_0(n) = \left(1 - \frac{1}{n_e}\right)^n \quad (2)$$

$$P_1(n) = {}_nC_1 \frac{1}{n_e}\left(1 - \frac{1}{n_e}\right)^{n-1} \quad (3)$$

$$P_{2+}(n) = 1 - \left(1 - \frac{1}{n_e}\right)^n - {}_n C_1 \frac{1}{n_e}\left(1 - \frac{1}{n_e}\right)^{n-1} \quad (4)$$

Here, ${}_nC_k$ indicates the number of combinations from n things taken k at a time. The readout success probability (P_1) is maximized when the estimated number is equal to the actual number, and, in the same manner as DFSA, it approaches $1/e$ if the actual number is sufficiently large.

Like DFSA, when the readout trial time does not vary, P_1 is set to the maximum conditions ($n_e = n$), and the maximum readout speed can be attained.

If the readout trial time changes (for example, t_{out} is shorter than t_{suc}), then the maximum readout speed cannot be attained when P_1 has its maximum value. If t_{col} and t_{suc} are supposed to be equal (this applies when a collision is detected due to a readout error), then they can be formulated in the following way.

Firstly, get the timeout-contribution-factor indicated by $(t_{suc} - t_{out})/t_{suc}$, then get Δ, which is the response-probability-variation from the optimal-resonse-probablity when readout-trial-time does not change, using the following formula.

$$(1 - \Delta)e^{\Delta} = \frac{t_{suc} - t_{out}}{t_{suc}} \quad (5)$$

Figure 5 shows relation between response-probability-

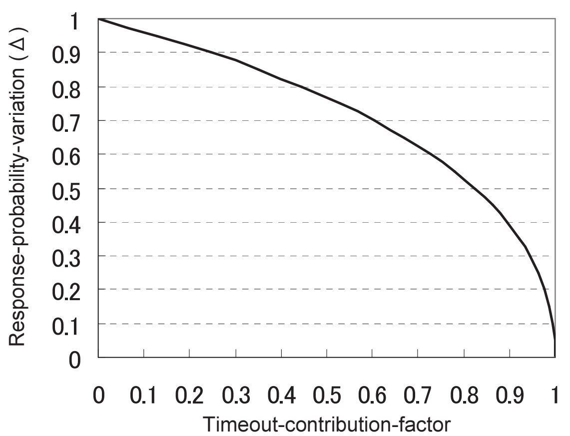

Fig. 5. Response-probability-variation and timeout-contribution-factor

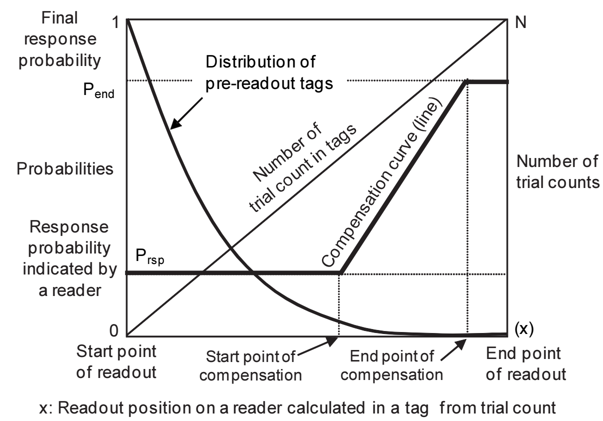

Fig. 6. Outline of response probability compensation

variation and timeout-contribution-factor. By using this response-probability-variation Δ, each optimal probability (the timeout probability P_0^{opt}, single-response probability P_1^{opt}, and collision probability P_{2+}^{opt}, response probability of tags P_{rsp}^{opt}), as well as the average trial time $\overline{t_{tsc}}$ and the average readout time $\overline{t_{read}^{opt}}$ can be obtained as follows, where it is assumed that $n \gg 1$ and $n_e \approx n$.

$$P_0^{opt} = \frac{1}{e^{\Delta}} \tag{6}$$

$$P_1^{opt} = \frac{\Delta}{e^{\Delta}} \tag{7}$$

$$P_{2+}^{opt} = 1 - P_0^{opt} - P_1^{opt} \tag{8}$$

$$P_{rsp}^{opt} = \frac{\Delta}{n} \tag{9}$$

$$\overline{t_{tsc}} = \frac{1}{e^{\Delta}}(t_{out} - t_{suc}) + t_{suc} \tag{10}$$

$$\overline{t_{read}^{opt}} = t_{suc} e^{\Delta} \tag{11}$$

The optimal response probability becomes a multiple of Δ ($0 < \Delta \leq 1$) for the optimal value ($1/n$) when the readout-trial-time does not change. The estimation process of pre-readout number of tags mentioned above also gives the optimal value (n/Δ), which refers to the pseudo-estimated number m. For a stationary system, the ratio of m to n ($= 1/\Delta$) is subtracted from the estimated number when there is a successful readout.

D. Simulation Conditions for a Stationary System

The readout request transmission time from the reader is set to 1 [ms]; the timeout detection time is set to 1 [ms]; and the readout response transmission time for the tags is set to 5 [ms]. The simulation assumes tags of the vicinity coupling type having a transmission speed of about 26 [Kbps]. The transmission time assumed for the readout request is equivalent to the 26-bit transmission time including overhead. The transmission time assumed for the readout response is equivalent to the 130-bit transmission time including overhead. At this time, the t_{suc} and t_{col} values (readout request transmission time + readout response transmission time) are 6 [ms]; the t_{out} value (readout request transmission time + timeout detection time) is 2 [ms]; and the response-probability-variation Δ becomes 0.6530. As mentioned above, the time required for readout confirmation was set to 0 [ms] since it could be concatenated to the following readout request. The *dfactor* and *ifactor* were set as 0.9796 and 1.080, respectively, according to the best simulation results. Here, the optimal relation between *dfactor* and *ifactor* is used in Ref. [6].

E. Analysis and Simulation of RPCM in Moving System

The assumption that the number of pre-readouts is sufficiently large cannot be employed. Furthermore, accurate estimation of the number of pre-readouts cannot be assumed since estimation delays are incurred in the estimates. This means that this system is a non-linear with delay elements. Except such case that can be assumed linear without delay element, analysis of a moving system is difficult, and its performance was confirmed using a simulation. As for such exceptional cases, analytical aspects are given with these limitations in followings.

F. Probability Response Compensation Method

Figure 6 shows an overview of the probability response compensation method. The method assumes that there are very few pre-readout tags in the vicinity the conveyor belt exit. The tags response probability is increased autonomously, in case that have not been readout even when they reach the vicinity the conveyor belt exit. The function of the tags become complicated, but there is a significant effect.

Each tag counts the number of readout trials after entering the readout area and calculates its own position. The actual number of readout trials depends on the conditions and is variable, even if the readout position remains constant.

Although the processing of the tags is complicated, the immediately prior readout results (timeout, single-response, collision) are attached to the readout request from the reader,

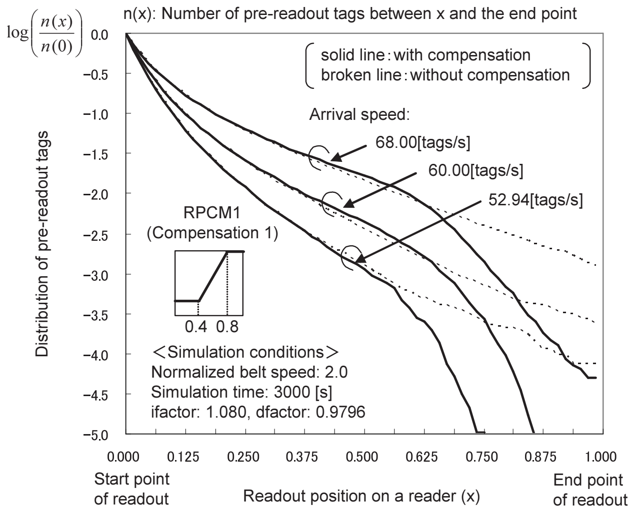

Fig. 7. Distribution of pre-readout tags with RPCM

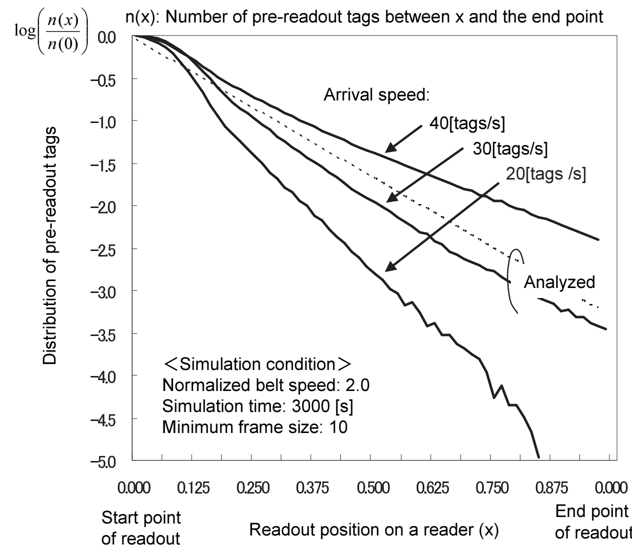

Fig. 8. Distribution of pre-readout tags with DFSA (ex.1)

and more precise position estimation is possible if the tag calculates the elapsed time based on this additional information. However, such highly accurate position estimation was not assumed in the following simulation.

The response probability compensation is controlled using the compensation start point, the compensation end point, the final compensation value (final response probability) and the order of the compensation curve.

IV. Moving System Simulation and Evaluation

The following was verified using a dedicated simulator for RPCM and DFSA. The conditions used for evaluating a stationary system were also used for the attributes of the reader. The tags move at a fixed speed on the conveyor belt and enter the readout area of the reader according to a Poisson distribution with an average arrival speed R_{in} [tags/s]. The time for remaining within the readout area was set to 0.5 [sec]. Average values during 3000 [sec] simulation will be shown.

A. RPCM Readout Simulation

Figure 7 shows an example of the pre-readout tag distribution (logarithmic display) for RPCM confirmed by the simulation. The number of readouts remainder (relative value) are shown at the readout end point ($x = 1$). Two curves are shown for when response probability compensation was performed (solid line) and when it was not performed (broken line) for three different arrival speeds. Response probability compensation starts at $x = 0.4$ and finishes at 0.8. The final compensation value is 1, and the order of the compensation curve is 1 (i.e., a straight line).

The slope after the midpoint is gradual compared to the steep inclination in the area near the readout start point. The reason for this is that a small number of pre-readouts are concentrated in the area around the start point. After midpoint, the number of pre-readouts is large from the start point, thus the readout ratio together with the readout success probability decreases.

But, the number of pre-readout tags can decrease rapidly during the latter half of the readout when response probability compensation is performed. It needs the conditions that the number of pre-readout tags was low enough in the latter half of the readout.

The estimation for the number of pre-readout tags, obtaining approximate values from additional information such as an image, is for further study.

B. DFSA Readout Simulation

A pre-readout number n is estimated by DFSA, and this n is specified as frame size when the readout request was performed. The timeout probability (P_0 = number of timeout slots divided by the frame size), the collision probability (P_{2+} = number of collision slots divided by the frame size), and the frame size (=n_e) should be substituted into formulas equivalent to P_0 (Eq. 2) or P_{2+} (Eq. 4) to estimate the number of pre-readouts n by the reader. The number of successful readouts (the number of single-response slots) is deducted from n, thus the frame size is assigned as n when next readout request is performed.

The minimum frame size must also be set to $fs_{\min}$ for the DFSA method in order to support rapid increases in the number of tags. Figure 8 shows the distribution of pre-readout tags when the minimum frame size $fs_{\min}$ is set to such a large size as 10.

The number of pre-readouts can only be estimated using the timeout probability since collisions rarely happen in this situation. For this reason, the simulation only uses the timeout probability.

The readout speed is slow in the area immediately after the arrival, which is difference from the RPCM. When T_0 is set equal to the frame request interval, there is the effect due to the readout not being performed for a period of time $0 \sim T_0$ after an arrival. Because the readout request timing and the arrival timing occur independently, the influence can be approximated

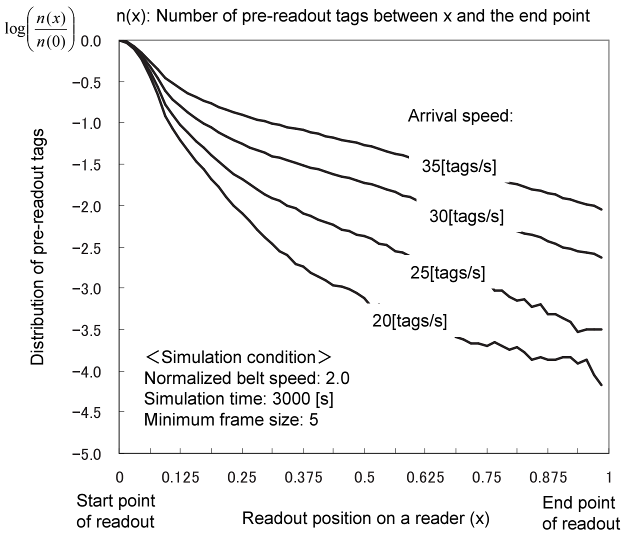

Fig. 9. Distribution of pre-readout tags with DFSA (ex.2)

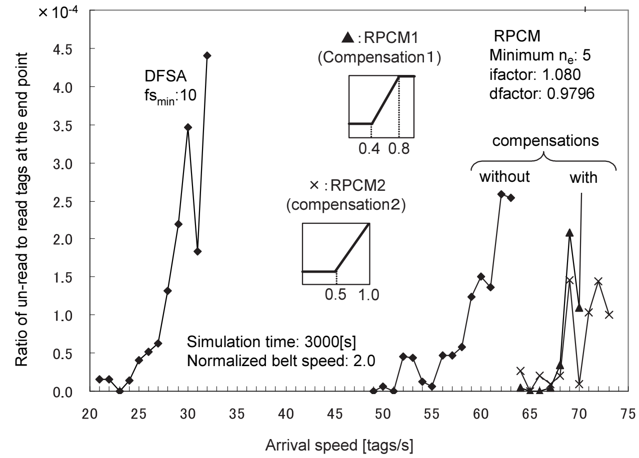

Fig. 10. Ratio of unread to read tags

by $T_0/2$. Except such effect, the distribution can be analyzed with limit accuracy as follows.

$$n_x(x) = n_x(0)exp\left(-\frac{x}{v_{belt}T_0}\left(1-\frac{1}{fs_{\min}}\right)^{n-1}\right) \quad (12)$$

$T_0 = fs_{\min}t_{slot}/(1 - R_{in}t_{suppress}) + t_{req}$, and n can be obtained from $n\left(1 - 1/fs_{\min}\right)^{n-1} = R_{in}T_0$.

As Eq. 12 shows, the distribution goes low with the speed and the minimum frame size decrease. When the conditions indicated by Eq. 12 stands, the incidence rate can be predicted for the number of readouts remainder. The differences of n (T_0) between the analyzed and the observed in the simulation were 0.5-14% (0.5-1.8%), respectively. The error relating to n was large. It is necessary to pay careful attention to the accuracy of Eq. 12.

Figure 9 shows the distribution of pre-readout tags, when the minimum frame size $fs_{\min}$ is set to such a small size as 5. The readout success probability is large. The distribution density rapidly goes low around the readout start point, but it slowly goes low after this area.

Because the estimation time delay of pre-readouts in DFSA is large compared to the RPCM, and the tags un-read due to a rapid increase in the number of arrivals spend a long time in the pre-readout condition. Eventually, pre-readouts remain in more numbers than that shown in Fig. 8.

This ($fs_{\min} = 5$) is a non-linear system with time lags, making it difficult to perform a high precision analysis.

V. Comparison and Evaluation of RPCM and Other Methods

- Although readout confirmation time (RPCM) and readout suppression time (DFSA) are required to avoid unnecessary readouts, in the case of the RPCM it becomes practically zero since it can also be used as the readout request. If there is no-response, the slot time cannot be shortened using FSA or DFSA, but using the RPCM the next readout request can be output immediately after timeout. In case of stationary system, these effects bring maximum RPCM readout speeds 86.8 [tags/s], while muximum DFSA speed is 53.8 [tags/s], which indicate 1.61 times faster readout speed in RPCM. Note that Eq. 1, Eq. 11 and the simulation conditions for stationary system are used here.
- With DFSA, the operation of estimating the number of pre-readouts is slow, and in the case of a moving system, a rapid increase in the number of tags results in an increase in the number of pre-readouts. To avoid this, the entire readout success probability decreases when a large number is used for the minimum frame size.
- In the case of a moving system, the RPCM can compress the number of pre-readouts around the readout end point using response probability compensation. Figure 10 shows a comparison of the readout remainder rates (i.e., the ratio of unread to read at the end point) that were obtained for various conditions. Here, an arrival speed that brings less remainder rate than the certain threshold is defined as the readout speed of a moving system. For example, when the readout remainder rate of 2.00×10^{-5} is taken as the threshold, the speeds become 24 [tags/s] for DFSA, 51 [tags/s] for RPCM (without compensation), 67 [tags/s] for the RPCM (compensation 1), and 68 [tags/s] for the RPCM (compensation 2). In other words, the RPCM can attain a speed that is 2.13 times faster than that of DFSA (without compensation), 2.79 times faster (compensation 1), and 2.83 times faster (compensation 2). Also, on a belt that is advancing at a slow enough speed, each readout speed converges to the maximum speed of a stationary system. The ratio of maximum speed at stationary system is 1.61, and thus there is a greater difference in performance when the belt speed is fast.
- Influence of estimation accuracy of pre-readout tags to readout performance is not reported in this paper. As mentioned before, the initial estimation error hardly increase readout time in a stationary system with a large number of pre-readout tags. On the contrary, we have observed that the readout speed can be improved in a

moving system by adapting the estimated number of pre-readout tags to the actual one in a real-time fashion. Though there are some studies on estimation of the number of pre-readout tags [17], [18], [20], we have not compared them with RPCM quantitatively due to the differences of system condition: RPCM utilizes the characteristics that the timeout check time is shorter than the readout time. We plan to further investigate the estimation accuracy and speed under more realistic situations taking into account the realistic tag distribution on the conveyor belt.

- K. Cha et al. proposed power control algorithms to avoid data collisions among multiple readers [10]. In this paper, we does not focus on how the power control in a reader affects the performance of RPCM. We expect that the improvement of reading speed by RPCM results in saving radio resources, and saved resources can contribute to the reader collision problem.

VI. Conclusions

This paper discussed how the tag readout speed could be increased in a moving system considered from the viewpoint of preventing collisions. When the readout speed of moving system was set to the arrival speed, achieving the number of remainder below a certain threshold, a readout speed of 2.5 times or more than that of the existing collision avoidance method could be achieved under the proposed conditions used for the RPCM.

Some may be of the opinion that collision avoidance using existing methods is enough if the radio resources are sufficient. However, effective utilization of radio resources should be considered in future advanced applications. Then, this technology will be advantageous.

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