Radio-Frequency Identification (RFID) Technology In Public Transportation System

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Abstract—Automated passenger tracking in public transportation systems can be used to estimate the short-term demand and, thereby, to optimize the fleet schedule in real time. It can also be used to determine the origin–destination matrix and to maintain statistics of each passenger's transportation habits over time, thus enabling enhancements in long-term planning. However, ubiquitously tracking passengers throughout a network requires the ability to recognize them at single locations in the network. In this paper, study the merits of realizing this task by means of radio-frequency identification (RFID) technologies. Forty volunteers carried RFID tags of the norm EPC Gen2 in their backpacks, wallets, pockets, and hands through a mockup of a bus door equipped with four reading antennas. Setups with one and two rows of persons walking through the portal were evaluated. The RFID tags were embedded in laminated plastic cards. Single-tag cards embedded with a single EPC Gen2 tag and dual-tag cards that also contained a traditional mifare tag were used. Recognition statistics of passengers for all the combinations of one, two, three, and four antennas are presented. The recognition percentages are mainly influenced by the antenna position and radiation pattern and by the line-of-sight conditions between the tag and the antennas.

Index Terms—Automatic passenger counting (APC), EPC Gen 2, Intelligent transportation systems, Mifare, passenger tracking, pedestrian modeling, RFID, smart cards.

I. INTRODUCTION

Public transportation systems could greatly benefit from a technology that allows automatic tracking of every passenger in real time. In effect, given the tracking information and adequate data mining techniques, the historical behavior of every passenger could be synthesized and used to predict demand. Short-term demand could adaptively be predicted—and reacted to—as passengers show up at expected times and expected stations for their regular daily trips, thus providing clues about their likely destinations and probable return trip times. This vision is becoming plausible as major cities in the world adopt radio-frequency identification (RFID)

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This action allows easy registration of the boarding station and time of each passenger. In some systems, like the system in London, U.K., passengers also have to validate their trips at alighting time.

Unfortunately, the more common case is that passengers alight without any sort of fare validation. This makes recording alightings more difficult, because reading a smart card requires passenger participation, as the cards must be held against a reader antenna at a distance not further than 10 cm. This very short range limitation is imposed by design to avoid access by unwanted parties to the balance stored on the tag. A promising RFID technology for recording alightings (or boardings) without passenger participation is EPC Gen2 [2], which were developed to establish a standard for RFID applications in supply chains. EPC Gen2 tags operate in ultrahigh frequency (UHF) (860–960 MHz) and can be read at a distance of several meters. Contrary to the complex set of functions supported by smart cards like Mifare, including data encryption, on-tag arithmetic for balance accounting, and read/write capability, EPC Gen2's purpose is simply to provide an inexpensive identification number with minimal support for other functions.

In this paper envision that embedding an EPC Gen2 tag into cards that also hold a Mifare tag can provide a feasible cost-efficient solution to the problem of recognizing and tracking passengers in the many public transportation systems in which alightings do not get registered. A basic performance assessment of EPC Gen2 for an application like this is made in [2], where tag-detection statistics are gathered with three persons crossing a portal carrying EPC Gen2 tags hanging from their necks. The results provide some insight into the readability of the cards for the application studied here, but the statistical significance of those results is weak, and further studies are clearly needed. The contribution of this paper is a performance evaluation of commercial off-the-shelf EPC Gen2 hardware used to recognize people passing through a portal that is similar in size to a bus door. Our experimental data were collected with 40 persons carrying two kinds of cards: "single-tag cards," which are credit-card-sized laminated plastic cards that contain a single EPG Gen2 tag, and "dual-tag cards," which also contain a Mifare tag (see Fig. 1). Our study assesses the readability of the cards under different conditions involving the most common locations where smart cards are carried (in their backpacks, pockets, wallets, and hands). It is also considered the effects of reader antenna location around the portal and the crowdedness of people passing the portal. This paper also provides insight into hardware specializations that could further enhance the measured performance and discusses system-wide implementation issues and costs. The performance measures presented may serve as a benchmark for other approaches that seek alternative solutions to the problem of people recognition (e.g., face recognition by computer vision or as a source of empirical data for simulating transportation systems with an ability to track passengers.

II-EXPERIMENTAL METHODS

In the system of EPC Gen2 RFID recognition, each of the 40 passengers received two cards: one dual-tag card (colored black) and a single-tag card (colored red). The portal was located at the entrance door of a midsized room of dimensions 9.5 × 8 m with an exit door at the opposite side. The volunteers were instructed to walk in a row, entering the room through the portal and exiting it through the other door. One trial consisted of five laps. A trial thus consists of 200 passages through the portal (40 persons × 5 laps). Six trials were conducted, each time placing one of the two cards in one of the following three positions, while the other card was carried in the hand:

1) Card in the wallet in the backpack.
2) Card in the wallet in the pants' right back pocket.
3) Card loose in the pants' right back pocket.

According to a survey realized among 230 university students, these four locations (including handheld cards) are the most common ones and encompass 84.5% of the cases. It is to be noted that the measurements collected for handheld cards amount to 600 passages through the portal (40 persons × 5 laps per trial × 3 trials and one trial for each card location).The six trials described earlier were repeated for two walking modes:

1) All 40 volunteers walking in a single row
2) All 40 volunteers walking in couples.

The data for each trial were acquired with all four antennas online. Individual performance measures per antenna or per combination of two antennas (six combinations), three antennas (four combinations), or all four antennas were obtained by filtering the data offline after the trials.

III-EXPERIMENTAL RESULTS

The recognition percentages obtained in all the trials are presented in Tables I–IV, which are sorted by the number of antennas for all 15 possible antenna combinations. The antenna combinations are indicated by the icons in the leftmost column. Each black corner in an icon represents an antenna in that position of the portal that is part of the combination (e.g. denotes statistics that only consider the upper left antenna). The percentages were determined by averaging the five per-lap recognition rates of each trial. The recognition rate of each lap is the number of detected tags divided by the total number of tags (40). The margin of error was calculated considering standard Bernoulli trials and a confidence level of 95.4% [19]. Bold values indicate the best alternative among all the ones that have the same number of antennas. A detailed analysis of the performance shown in Tables I to IV is carried out next.

A. *Effect Of Card Location*

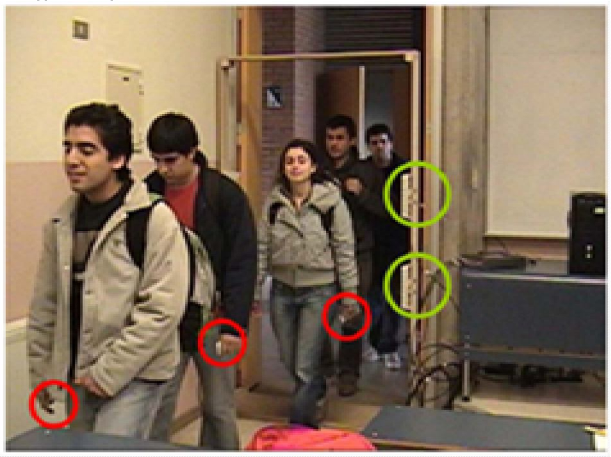


Fig 1 Snapshot of a single-row trial.

1) Handheld cards:

These cards have a rather unobstructed exposure to the antennas (line of sight). Therefore, the corresponding single-tag statistics in Table I represent the best-case recognition performance that can be achieved with current-day off-the-shelf hardware for the application under study. By inspecting Table I, two antennas positioned at hip-height yield a 98% chance of recognition. The lower antennas have higher percentages of recognition than the upper ones because the participants tended to walk with their arms hanging. This suggests that the relative position between tags and antennas is a relevant design aspect. Furthermore, a degradation of 4% can be attributed to the loss of line of sight caused by a second person walking through the portal (see Table II). In comparison, the recognition percentage for handheld dual-tag cards with both lower antennas is 96% in one-row measurements (see Table III). Hence, there is a 2% performance loss over single-tag cards. Similarly, the loss attributable mainly to line-of-sight obstructions from a second person in the portal is 7% with dual-tag cards. It concludes that even under favorable propagation conditions, EPC Gen2 tags suffer some performance loss from colocated Mifare tags

2) Cards Located In the Wallet Inside The Backpack:

It observes that the best recognition performance is obtained with configurations that contain at least one of the upper antennas. This coincides with the higher relative position of the cards in the backpack compared with the handheld case. This confirms that the percentage of

Table-I

Recognition percentage for single-tag cards: one row

	Handheld	Wallet-Backpack	Wallet-Pocket	Loose-Pocket
	61% ±4,0%	**89%** ±4,4%	12% ±4,6%	25% ±6,1%
	56% ±4,1%	85% ±5,0%	13% ±4,8%	17% ±5,3%
	84% ±3,0%	81% ±5,5%	32% ±6,6%	44% ±7,0%
*	**92%** ±2,2%	80% ±5,7%	**92%** ±3,8%	**97%** ±2,4%
	72% ±3,7%	91% ±4,0%	17% ±5,3%	31% ±6,5%
	87% ±2,7%	89% ±4,4%	32% ±6,6%	46% ±7,0%
	87% ±2,7%	88% ±4,6%	33% ±6,6%	47% ±7,1%
	94% ±1,9%	**92%** ±3,8%	92% ±3,8%	97% ±2,4%
	93% ±2,1%	90% ±4,2%	92% ±3,8%	97% ±2,4%
*	**98%** ±1,1%	85% ±5,0%	**93%** ±3,6%	**98%** ±2,0%
	90% ±2,4%	91% ±4,0%	33% ±6,6%	49% ±7,1%
	94% ±1,9%	**93%** ±3,6%	92% ±3,8%	97% ±2,4%
	99% ±0,8%	90% ±4,2%	**93%** ±3,6%	**98%** ±2,0%
*	**99%** ±0,8%	92% ±3,8%	**93%** ±3,6%	**98%** ±2,0%
	99% ±0,8%	**93%** ±3,6%	**93%** ±3,6%	**98%** ±2,0%

Table- II

Recognition percentage for single-tag cards: two rows

	Handheld	Wallet-Backpack	Wallet-Pocket	Loose-Pocket
	54% ±4,1%	**89%** ±4,4%	7% ±3,6%	15% ±5,0%
	51% ±4,1%	87% ±4,8%	9% ±4,0%	21% ±5,8%
	82% ±3,1%	77% ±6,0%	25% ±6,1%	36% ±6,8%
*	**86%** ±2,8%	82% ±5,4%	**80%** ±5,7%	**82%** ±5,4%
	64% ±3,9%	94% ±3,4%	11% ±4,4%	28% ±6,3%
	85% ±2,9%	91% ±4,0%	26% ±6,2%	38% ±6,9%
	86% ±2,8%	90% ±4,2%	27% ±6,3%	40% ±6,9%
	89% ±2,6%	**95%** ±3,1%	81% ±5,5%	83% ±5,3%
	88% ±2,7%	91% ±4,0%	80% ±5,7%	83% ±5,3%
*	**94%** ±1,9%	89% ±4,4%	**85%** ±5,0%	**84%** ±5,2%
	87% ±2,7%	94% ±3,4%	28% ±6,3%	41% ±7,0%
	90% ±2,4%	**96%** ±2,8%	81% ±5,5%	83% ±5,3%
	95% ±1,8%	94% ±3,4%	**85%** ±5,0%	**84%** ±5,2%
*	**95%** ±1,8%	95% ±3,1%	**85%** ±5,0%	**84%** ±5,2%
	95% ±1,8%	**96%** ±2,8%	**85%** ±5,0%	**85%** ±5,0%

Table-III

Recognition percentage for dual-tag cards: one row

	Handheld	Wallet-Backpack	Wallet-Pocket	Loose-Pocket
	31%±3,8%	**86%** ±4,9%	7% ±3,6%	3% ±2,4%
	32%±3,8%	76% ±6%	3% ±2,4%	3% ±2,4%
	71%±3,7%	83% ±5,3%	18% ±5,4%	7% ±3,6%
*	**81%** ±3,2%	71% ±6,4%	**78%** ±5,9%	**64%** ±6,8%
	42% ±4%	93% ±3,6%	8% ±3,8%	4% ±2,8%
	74% ±3,6%	**94%** ±3,4%	18% ±5,4%	7% ±3,6%
	75% ±3,5%	**94%** ±3,4%	18% ±5,4%	8% ±3,8%
	83% ±3,1%	91% ±4%	**78%** ±5,9%	64% ±6,8%
	82% ±3,1%	87% ±4,8%	**78%** ±5,9%	64% ±6,8%
*	**96%** ±1,6%	88% ±4,6%	**78%** ±5,9%	**65%** ±6,7%
	76% ±3,5%	**97%** ±2,4%	18% ±5,4%	8% ±3,8%
	83% ±3,1%	94% ±3,4%	**78%** ±5,9%	64% ±6,8%
	97%±1,4%	95% ±3,1%	**78%** ±5,9%	**65%** ±6,7%
*	**97%** ±1,4%	94% ±3,4%	**78%** ±5,9%	**65%** ±6,7%
*	**97%** ±1,4%	**97%** ±2,4%	**78%** ±5,9%	**65%** ±6,7%

Table IV

Recognition percentage for dual-tag cards: Two rows

	Handheld	Wallet-Backpack	Wallet-Pocket	Loose-Pocket
	26% ±3,6%	67% ±6,6%	3% ±2,4%	2% ±2,0%
	24% ±3,5%	83% ±5,3%	6% ±3,4%	0% ±0,0%
	66% ±3,9%	65% ±6,7%	14% ±4,9%	15% ±5,0%
*	**69%** ±3,8%	**83%** ±5,3%	**72%** ±6,3%	**67%** ±6,6%
	33% ±3,8%	91% ±4,0%	6% ±3,4%	2% ±2,0%
	69% ±3,8%	75% ±6,1%	15% ±5,0%	15% ±5,0%
	68% ±3,8%	90% ±4,2%	16% ±5,2%	15% ±5,0%
	73% ±3,6%	**94%** ±3,4%	72% ±6,3%	67% ±6,6%
	70% ±3,7%	92% ±3,8%	72% ±6,3%	67% ±6,6%
*	**89%** ±2,6%	92% ±3,8%	**76%** ±6,0%	**70%** ±6,5%
	70% ±3,7%	91% ±4,0%	16% ±5,2%	15% ±5,0%
	73% ±3,6%	**97%** ±2,4%	72% ±6,3%	67% ±6,6%
	90% ±2,4%	95% ±3,1%	**76%** ±6,0%	**70%** ±6,5%
*	**90%** ±2,4%	94% ±3,4%	**76%** ±6,0%	**70%** ±6,5%
	91% ±2,3%	**97%** ±2,4%	**76%** ±6,0%	**70%** ±6,5%

recognition is highly sensitive to the radiation pattern of each antenna relative to the portal. The performance observed in two-row measurements and that in single row measurements are similar. This coincides with intuition, because when one or two backpacks are crossing the portal and are best positioned for the antennas to detect the tags inside, the persons carrying the backpacks are already out of the line-of-sight path between antennas and tags. The percentages of recognition of dual-tag cards are also similar to their single-tag counterparts. This indicates that the line-of sight obstructions caused by wallets and backpacks dominate over the mutual degradation encountered before between tags in dual tag cards. Overall, the percentages of recognition are consistently above 92% for the best-performing configurations with two or more antennas.

3) Cards Located In The Pants Back Pockets:

The closeness of the cards to the human body hampers their reading range because the human body, which is mostly composed of water, is a poor carrier of radio waves. Whether the card is additionally in a wallet or not may have positive or negative effects on a card's detectability. On the one hand, a wallet keeps the card somewhat away from the body, facilitating energizing the tag. On the other hand, close-by metallic elements such as coins can degrade the electromagnetic tuning of a tag's antenna. The wallet-pocket and loose-pocket statistics with one antenna show a similar pattern in all four tables: The highest percentage of recognition is obtained with the lower right antenna, while only marginal recognition is achieved with all the others. Furthermore, configurations with two or more antennas perform best when the lower right antenna is present, but that performance is not significantly better—if it is better at all—than that with the lower right antenna alone. Compare this fact now with the corresponding handheld performance: Recognition of handheld cards with the lower right antenna is only slightly better than that for the two pocket cases (they all have similar line-of-sight exposure to the lower right antenna), but handheld recognition clearly benefits from adding more antennas, because handheld cards have better line-of-sight exposure to those antennas than cards in the pocket. This difference reveals that the human body mainly hampers the tag recognition if it obstructs the line-of-sight between tags and antennas and that its effect is marginal in the case with good line of sight, even if the card lies in a pocket very close to the skin.

B. EFFECT OF THE DISTANCE BETWEEN CARDS AND READER ANTENNAS

When walking in a single row, participants passed the portal through the middle, exposing their tags located in the right back pants pocket at an approximate average distance of 45 cm from antenna and about 65 cm from antenna. The results from trials with two rows of people can be subdivided between the participants that walked in the right row and the ones that walked in the left row. For those in the right row, the card was exposed without obstruction to antenna from about 10 to 15 cm and from about 85 to 90 cm to antenna, with a partial obstruction from the participant walking in the left row. Similarly, for those in the left row, the cards in the right pocket passed antenna about 65–70 cm away (in this case, partially obstructed by the participant walking in the right row) and about 30–35 cm away from antenna. By splitting the data this way, observe that, in wallet-pocket and loose-pocket modes, antenna has consistently better percentage of recognition than antenna (see Table 3.5). This indicates that a tag is easier to detect by a more distant antenna with line of sight to the tag than by a closer antenna whose line of sight is obstructed by the person carrying the tag. Conclude again that line-of-sight exposure is a critical factor in the recognition performance.

C. EFFECT OF ANTENNA HEIGHT

Consider dividing the participants into three equal-size groups according to the height of the card in each participant's pocket with respect to the floor (this information was recorded for all participants). The resulting groups are

1) 69–79 cm, 13 persons (six men, seven women);

2) 80–82 cm, 13 persons (six men, seven women);

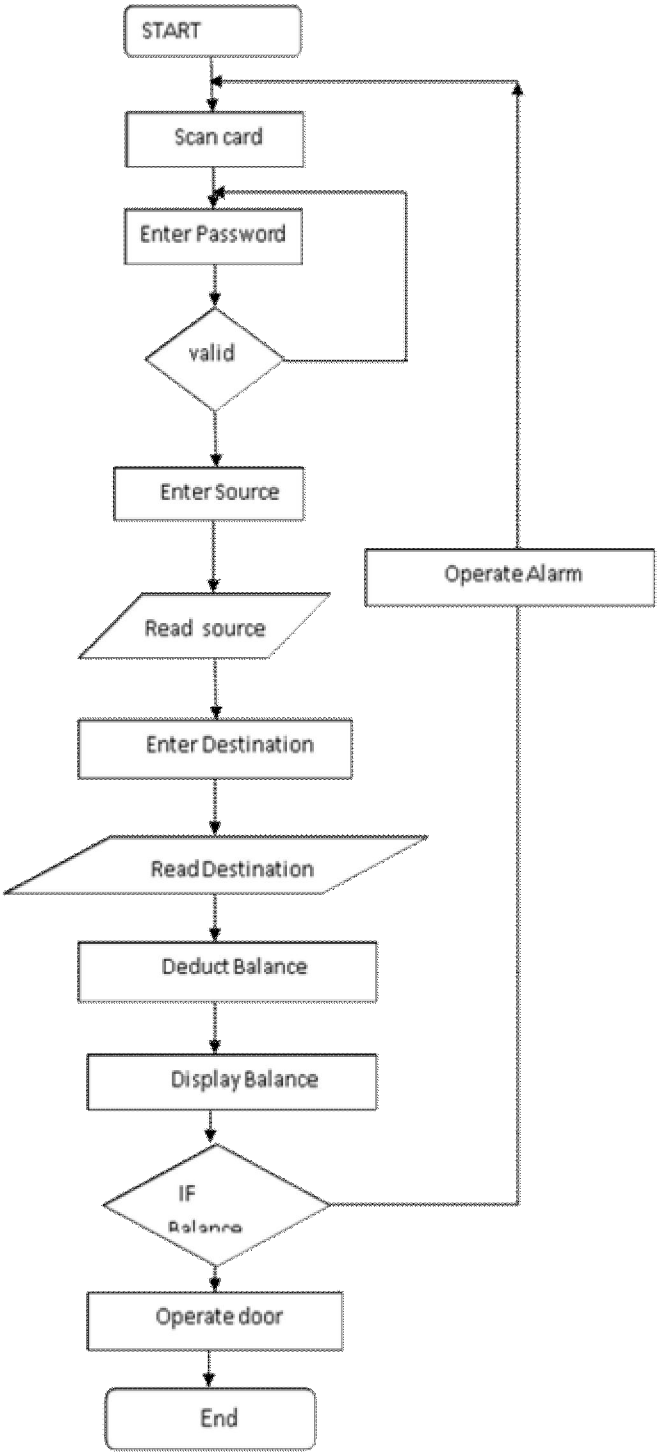
3) 83–87 cm, 14 persons (seven men, seven women).

Recalling that those antennas were mounted at 78-cm height, it becomes clear that the percentage of recognition is quite sensitive to the relative position of the cards with respect to the radiation pattern of the antennas. We conclude again that antenna design is a key aspect for the application under study. (A conclusion that 78 cm is an ideal antenna height would be misleading, because the average height depends on ethnic and socioeconomic factors of the population.)

IV- IMPLEMENTATION:

This paper proposed mifare based RFID for commuting in public transportation buses so that passengers will be recognized individually at a closer distance by the RFID reader (Interrogator). As opposed to EPC Gen2 RFID tags which could be recognized at several meters cannot be used in passenger recognition because several tags will be picked up at the same time from people other than passengers such as pedestrians and people waiting at bus stops. Hence we propose a system with mifare RFID tags for passengers who can be tracked accurately and efficiently. Thus the balance will be deducted from the mifare RFID tag for the journey he/she embarks This paper presented the mifare tag based RFID system for the passenger recognition with automated fare collection for the destination passenger's travel. It demonstrated the value of its interpreted by the corresponding subsystems to automate a number of processes. While such RFID tags are available, their high costs mainly confine their applications to high-valued objects, such as human beings. It believes that our proposed solution can be a key element of intrinsically complicated transportation systems that are being planned and developed. Thus the system has been designed with microcontroller, RFID module and power supply.

V-FLOWCHART



application in future public transportation systems. This paper also discussed the many benefits of our proposed mifare based RFID System can provide, including improvements in system scalability, information availability, automated monitoring and processing of sensitive information, and access control. This paper claim that these benefits can be achieved by employing RFID tags with more memory to encode information- rich data along with action scripts that can be

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