Ensuring Reliability in Vehicular Collision Avoidance Using Joint RFID and Radar-Based Vehicle Detection

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Abstract RFID tags are very essential for new generation automated vehicles. In this paper, three generations of RFID have been discussed with focus being on third generation that is used for vehicular applications. The main sensor for target detection in autonomous vehicle is automotive radar. Here, RFID-based vehicle detection and radar-based vehicle detection and their applications have been explored.

Keywords RFID · RADAR · Millimeter-wave · IFF · Smart vehicle

1 Introduction

A radio frequency identification (RFID) system works on the principle of a wireless radio link between a tag or transponder which contains details of the device to be identified, and a reader, that has transmitter and receiver [1]. RFID application at ultra-high-frequency (UHF) range is very popular worldwide for tracking of objects upto a range of 10 m. But large readers with big antennas are a drawback for UHF RFID. So, recent researches are concentrating more on the millimeter-wave range that has smaller antennas with highly directional narrow beam to detect targets. The use of radio waves started with the invention of radar around World War II. Radar works on the principle of searching and detecting a target with the help of radio waves and analyzing the received echo signal to obtain parameters of the target. First usage of RFID was the identification friend/foe (RFID) technology with passive RFID which was developed in Britain. This IFF technology is a surveillance system, present at aerodrome that uses millimeter-wave to identify whether any incoming

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aircraft is from an ally country or an enemy. This technology can be incorporated in smart vehicles for detection of target vehicles using radar and RFID. This paper is arranged in following manner, Sect. 2 overviews the working principle of RFID, Sect. 3 explains automotive radar, and Sect. 4 presents the innovative work initiated by the authors.

2 RFID

RFID transponders are mainly used for observation and tracking of objects. A reader is able to scan multiple tags simultaneously. The characteristics of RFID that make it better than barcodes are the non-line-of-sight operation, high-speed operation, ability to read, and write to tags and is provided with an unique ID.

A reader is made up of an antenna emanating EM waves and a RF module. RFID can operate either in near field where antenna operates in low or high-range frequencies or in far field where frequency range is ultra-high frequency (UHF) or microwave frequencies. In case of near-field operation, antenna on the reader produces EM field that causes inductive coupling of tag, and this changing magnetic flux induces current in tag. Subsequently, tag data is modulated to communicate with reader. In case of far-field tag-reader, communication is based on backscattered signal [2]. Tags could be initially in sleep mode and woken up by a UHF carrier signal transmitted by reader. Then, reader could transmit a query signal and obtain backscattered signal from tags and other clutter. After processing of backscattered signals, tags can be detected and localized, and finally, communication between reader and tag is established, as shown in Fig. 1. Field energy decreases proportionally to $1/R^3$ in near field and to $1/R$ in far-field scenarios.

$$\text{Distance limit between near and far field,} \quad R = 2D^2/\lambda \tag{1}$$

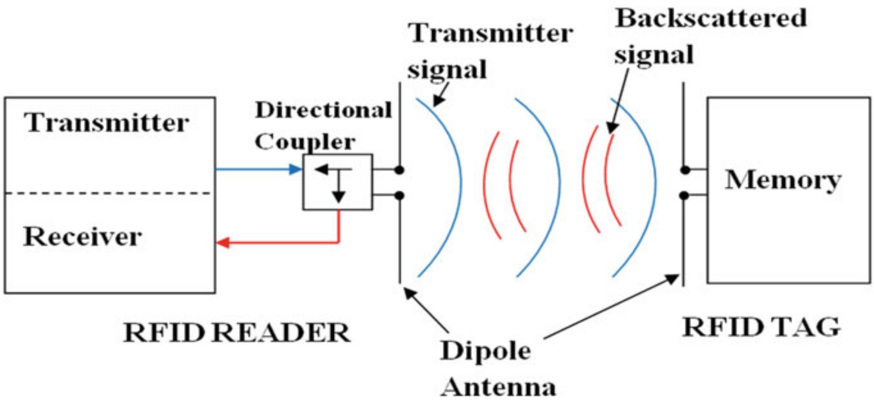

Fig. 1 Basic model of RFID functional block

where D = diameter of antenna, λ = wavelength of radio wave.

Every RFID tag on an object has a unique code called electronic product code (EPC) consisting of EPC standard of 96 bits.

- The first 8 bit header defines the tag version number
- Next comes the EPC manager of 28 bits containing the manufacturer's identification
- This followed by object class of 24 bits having product identification
- Lastly, the serial number containing the unit ID of 36 bits.

There are three types of tag, namely passive which collects power from reader's radiated power, semi-passive where battery provides power and active where battery provides power–transmitter present in tag. The power transmitted from reader and received by tag can be demonstrated as,

$$\mathrm{P}_{\mathrm{rec}} = P_{\mathrm{PA}} G_{\mathrm{TX}} G_{\mathrm{tag}} \left(\frac{\lambda}{4\pi d} \right)^2 \tag{2}$$

where P_{PA} = power of amplifier, G_{TX} = gain of transmitter antenna, G_{tag} = gain of tag, λ = wavelength of carrier signal, and d = distance between reader and tag.

2.1 RFID Generations

The three generations of RFID based on uses and technical constraints have been given in Table 1.

Table 1 RFID use cases

RFID uses	RFID 1st generation	RFID 2nd generation	RFID 3rd generation
Identification	Yes	Yes	Yes
Tracking	No	Yes	Yes
Localization	No	No	Yes
Bandwidth	Low (KHz)	Low (KHz)	Wide (GHz)
RF carrier	Low at 13.56 MHz	UHF carrier at 900 MHz	MMwave carrier at 60 GHz
Antenna beamwidth	Wide toward Omni directional	Narrow	Pencil beam (2°)
Triangularisation	Not applicable	Not applicable	Beamsteering so one reader is sufficient, thus lowering the cost. For UWB RFID, three readers are required

From Table 1, it can be observed that although generation-2 RFID can detect and track the tag position, it does not support localization of tag. Due to low bandwidth in UHF architecture, beamsteering for direction of arrival (DOA) measurements is not accurately measured. RFID of third generation provides ranging accuracy to tag localization by modulation of backscatter signal. But range-based localization requires range measurements from minimum three readers present at each concerned location. Thus, high-directivity millimeter-wave antennas can be integrated into RFID system, enabling the reader to scan surrounding environment and identify, track, and localize tagged objects.

Demonstration of first-generation RFID is the student attendance system used in college [3]. The system consists mainly of a RFID reader, a microcontroller board, and a LCD screen, and every student has her RFID tag each with a unique identification code. When the tag is brought near to the reader, it is identified and name of the student is displayed on screen. Another application is the contactless debit/credit cards like the contactless VISA cards which uses RFID and near-field technology for transactions. The consumer needs to bring the card within range of the terminal equipped with RFID reader and make payment safely.

Application of the second generation of RFID is the automatic toll collection system [4] already introduced in India. In this case, the RFID reader set up at toll booth will read the prepaid RFID tags attached to a vehicle's windshield, and automatically, the required toll amount will be deducted from the owner's linked bank account. This process will also ensure:

- Reduce traffic congestion at toll booths
- Save time and fuel
- Stolen vehicle detection since each vehicle is assigned a unique RFID tag number.

Manufacturers like Alien technologies have designed EPC Class 1 generation-2 RFID tag IC named as HIGGs 3 [5]. The IC provides 800 bit memory, reading sensitivity upto 18.0 dBm, and writing sensitivity upto 13.5 dBm, with enhanced security using a non-digital and non-duplicable 'finger-print' for better security.

The third generation RFID, along with providing localization, is applicable for longer-range communication due to millimeter-wave carrier. So, it can be used as vehicular RFID for identification of vehicles on road leading to safer travel. Millimeter-wave portable RFID reader containing antennas with almost pencil beam can scan the surrounding to identify and localize tags. The tag is identified by backscatter method as done with UHF carrier. The reader transmits a train of N pulses modulated by reader code 'r_n,' ($n = 0, 1, \ldots N$), to every steering direction. After every pulse transmission, reader's antenna is switched from transmitter to receiver to receive backscatter signal. The ith tag modulates the incident signal according to code (${t_n}^{(i)}$) and stored data information d_m. For localization, code synchronization is done, where received signal is multiplied with sequence composed by reader code and ith tag's code. Finally, reader transmits another pulse train to obtain the data stored in the tag, and received signal is filtered and time sampled to obtain necessary information. Figure 2 shows the process diagram.

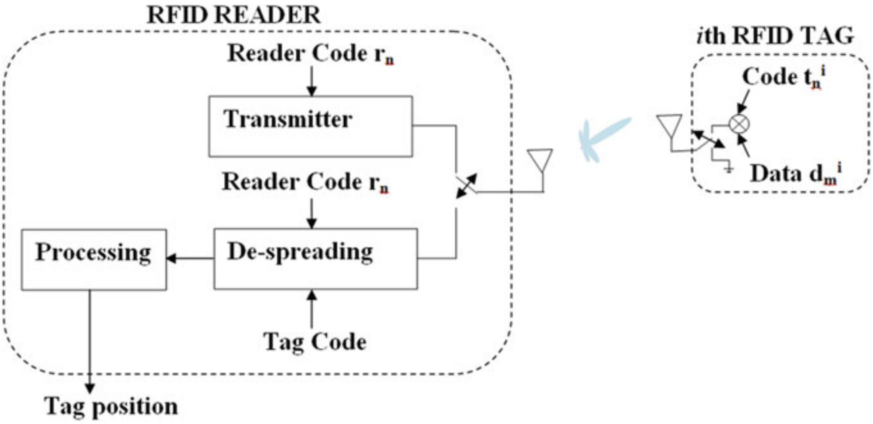

Fig. 2 Millimeter-wave RFID reader tag architecture for localization and communication

Guidi et al., [6] had validated this theory by placing fixed tag in a room and a single movable millimeter-wave reader. It can be compared to a road scenario with tag representing 1 fixed vehicle and shifting positions of second vehicle, i.e., the reader. Since millimeter-wave is used, localization error is minimum and range resolution is maximum. Exploiting this, they have positioned the vehicle very precisely only in x, y directions for performing two-dimensional localization. They had accounted for 36 steering directions for each position of reader, with angle step of 10° that covers the azimuth plane. Their outcome is interesting which shows that signal to noise ratio (SNR) is good if error in estimation of ranging, and steering angle is corrected. So, there is a reduction in false alarm rate. We have similar hardware equipments in our laboratory, so we have initiated related experiment which is stated later.

2.2 *Vehicular RFID*

Applications of vehicular RFID [7] mainly include management and control of vehicles, managing fleet of vehicles, and vehicular law maintenance.

- Control of vehicles: identification and localization of authorized vehicles
- Managing fleet of vehicles: tracking of different types of vehicles, controlling traffic lights, speed identification, and automatic toll booth operation
- Law maintenance: tracking of stolen vehicles possible because each vehicle has a unique RFID tag, also identification of owners whose road tax payment are due

Vehicular RFID can be used to measure the velocity of a vehicle by calculating the Doppler frequency shift from the backscattered signal.

3 Automotive RADAR

Automotive radars [8] are usually designed for working in 24 and 77 GHz frequency ranges. This spectrum is known as millimeter-wave frequencies as the wavelength lies in millimeter range. The advantages of operating in this band are wider bandwidth, better range resolution, and smaller sensor size suitable to be fitted in cars. Automotive radar is capable of performing functions like: (a) resolution of target (ability to identify separately two closely-spaced targets), (b) range resolution (ability to obtain different range values), (c) velocity of target measurement, and (d) determination of direction of arrival (DOA) of target echo. Along with these extremely important functions, the radar is robust to dirt, fog, and darkness and thus can operate unhindered under all weather conditions. So, for Advanced Driver Assistance System (ADAS) applications, namely Adaptive Cruise Control, park assist, front and rear traffic alert, blind spot detection, etc., in smart vehicles, radar is the primary sensor.

4 Work Initiated by the Authors

The work is based on third generation millimeter-wave RFID technology which is applicable for longer-range target detection, tracking, and localization. So, this RFID can be implemented in smart vehicle architecture for precise road vehicle identification with reduced false alarm rate. The working principle is similar to that of IFF technology. As per the paper discussed before, RFID can be used to identify tagged target vehicles. The reader can be mounted on another vehicle which is enquiring for information. Target detection is achieved by correlation of reader and tag codes. If the correlation value is 1, then the target is assumed to be 'friend' who can be identified and is willing to share its information. But if the correlation value is near to 0, then the target is assumed to be a 'foe' who does not want to be detected. Then, mode of operation will be changed to mm-wave radar, like a 28 GHz radar in our case, to obtain the range profile, velocity, and DOA of the target. The radar will send radio waves to the target, and on analysis of the received echo signal, target state parameters are obtained. Thus, using both RFID and radar modes, the problem of vehicle detection and localization will be solved with negligible false alarm rate leading to lesser collisions and safer driving.

5 Summary/Conclusion

This paper reviews the three generations of RFID, based on uses and technical constraints. The advantages of third generation mm-wave RFID are longer operational range, localization of tags, and beamsteering functions, along with smaller reader. The vehicular RFID can be implemented into vehicles for performing various tasks like other tagged vehicle identification and for automatic toll booth operation, and so on. The authors have initiated an innovative architecture where RFID and radar modes can be utilized in a switching manner to obtain information on a target vehicle. If the tag on target responds to reader on enquiring vehicle, RFID communication link is established. Otherwise, the enquiring vehicle will be equipped with radar also which can obtain the range, speed, and direction of the target, thus offering safety measures in driving.

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