AN RFID BASED VEHICLE IDENTIFICATION SYSTEM FOR PUBLIC TRANSPORT PRIORITY

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Abstract

Public Transport (PT) priority at traffic signals is important ITS measure implemented in modern adaptive traffic control systems with a goal to improve PT system performance. PT priority implementation demands that PT vehicle has to be identified at given location, therefore the essential part of traffic control system is an automatic vehicle identification. There are various technology approaches for vehicle identification and each one has its strengths and weaknesses. Recognized weaknesses of vehicle identification systems, which depend of respective system, are: inaccurate positioning, challenging installation, high price, traffic flow influence and weather influence. In collaboration with ZET (Zagrebački Električni Tramvaj) and MARETON d.o.o., RFID (Radio Frequency Identification) based identification system in combination with mobile communication was designed to partly overcome denominated weaknesses. Unlike various RFID based vehicle identification systems, which could be found in literature, tag in our design is buried in pavement, transponder and communication equipment are mounted on the tram vehicle. Numerous tags were tested, and the one with the best performance regarding robustness and reading accuracy was chosen to be installed in real conditions. Experimental results show that this identification system is robust in regard to installed tag and detection for given position. Furthermore the price of components is relatively low, so this vehicle identification design after developing interfaces with control system has the potential to serve for PT priority.

Keywords

Public Transport Priority, RFID, Vehicle Identification and Location, Tram

1. INTRODUCTION

Public transport (PT) is public service of great importance, which contributes to overall quality of life. Nowadays PT priority is important ITS measure with task to improve journey times and reliability of public transport. PT priority system is activated by the presence of the PT vehicle i.e. tram or bus. When a PT vehicle approaches the intersection, message with priority request is created and passed to traffic signal controller or traffic control centre. Control algorithm processes this message and decides how and when the priority will be granted. Common control priority actions are: extended green phase for PT vehicle, earlier green, and insertion of special phase (stage).

PT priority system includes integration of various components: vehicle identification (VI) and location system, communication with traffic control infrastructure, data processing, traffic control equipment and control algorithms, and corresponding interfaces. The task of vehicle identification and location system in PT priority is to undoubtedly identify PT vehicle at given location or continuously track a vehicle.

Vehicle identification and location can be achieved using a number of technologies: high-intensity light beacon (emitter/receiver system), radio beacon, VI systems based on GNSS (Global Navigation Satellite System) and cellular communications or other radio communication system, DSRC (Dedicated Short Range Communications), VI based on infrared beacon, inductive loop with vehicle mounted transmitter, inductive loop with vehicle classification algorithm, laser radar, VIP (Video Image Processing), VI based on sound detection systems, RFID (Radio Frequency Identifications) systems and WLAN-based Vehicle Identification [1,2]. Each of them has various strengths and weaknesses. For example, systems based on GNSS and some communication system continuously track a vehicle and have low installation demands regarding work on traffic infrastructure. But these systems could have significant errors in positioning, especially in urban environment. Reliable meters-level positioning is difficult to achieve in urban areas due to blocked direct line-of-sight of multi-constellation satellites, multipath interference of non-line-of-sight signals and quality challenges of conventional map-aided GNSS positioning, resulting in deteriorated accuracy [3].

RFID based systems are integrated in intelligent transport systems finding its use in toll collection, automatic vehicle location, public transport ticketing, speed violation detection systems , green wave system for public transport and emergency vehicles, detection of stolen vehicles [4-6] and many others.

VIP systems have adequate identification capability, but their performance is affected by obstacles, inclement weather and day to night transitions [1].

In Europe most recent systems use GPS in combination with some communication system as the main location technology for AVL (Automatic Vehicle Location). For example, Aalborg Auckland, London, Sydney use GPRS for communication, in Cardiff VHF and UHF radio, in Touluse
RFID system hardware consists of reader (transceiver) and tag elements. Communication between reader and tags is based on various international or industrial standards in diverse frequencies including low, high and ultrahigh. Tags can be active or passive. Active tags have power supply, while passive do not. Passive RFID systems have several strengths in vehicle identification: vehicle identification on exact position, no need for power supply, attractive cost-benefit ratio, various shapes of tags, and easy installation.

There are several factors that affect usage of RFID systems with passive tags. These are range of RFID system, data transfer time between reader and tag and performance of RFID system in real environment. Range of passive RFID elements is limited by reader characteristic, tag characteristics and propagation environment. Presence of electromagnetically hostile materials, such as metals and liquids, affects tags performance [8–10]. For successful data transfer, reader and tag have to be in range for a sufficient time.

In other words, successful tag reading depends on distance and relative speed between reader and tag and on other RFID system performances in real environment [12].

In this paper we propose vehicle identification system based on RFID where tag is buried in pavement and RFID reader is mounted on a vehicle, unlike common systems where reader is mounted on traffic infrastructure and tag is mounted on a vehicle. We tested performance of RFID system for a given reader and various tags regarding to range, angle of coverage, needed power in presence of water and reader movement speed. RFID reader installation on a tram and process of embedding tag in pavement is presented. At the end some advantages of these systems are described. This work is focused on tram traffic, so for application in bus traffic installation and some performances of RFID vehicle identification system could be different.

2. RFID BASED VEHICLE IDENTIFICATION SYSTEM DESIGN CONCEPT

Figure 1 shows RFID based vehicle identification system design concept. Main components of this system are: RFID reader and tag, on board unit, and communication with controller or traffic control centre. On board unit contains local computer, IBIS (Integrated Bus of vehicle Information System) interface, RFID reader interface and a communication module.

As shown on figure 1, a tag is buried into pavement on given location. Tag should be passive with capabilities to read and write. Each tag has unique IDC (Identification Code), which can be written in the tag user memory before or after installation. When tram passes over a tag, reader reads its data and forwards tag IDC to onboard unit. Local computer unit contains database in which each tag IDC is associated with tag location and distance from stop line. The second possibility is that the tag location and distance from stop line is written in tag memory. Based on acquired ID code, on board unit computer creates a message and sends it to local controller or traffic control centre.

![Figure 1: RFID based vehicle identification system concept](image-url)

Criteria for selection of commercially available RFID passive system are: range or read distance, data transfer rate, immunity to local electromagnetic interference, and performance in proximity to metal. Today there are two main passive RFID solutions, HF (High Frequency) at 13,56 MHz and UHF (Ultra High Frequency) 860-960 MHz. For each of them there are multiple international and industry standards. But UHF RFID is supported by prevalent EPC global industry-driven standard. Most UHF RFIDs have longer range (max. approx.- 10 m) due to radio wave based communication, unlike HF RFID (max. approx. 1m) which communicates via electromagnetic field. Furthermore UHF RFID has a higher data transfer rate.

When there is a relative velocity between reader and tag, limited time for tag reading is available. According to EPCglobal Class1 Gen2 standard, interrogator (reader) to tag communication bit rate is 26.7 kbps to 128 kbps, and tag to reader is 40 kbps to 640 kbps [11]. So read transaction time depends on these values. Transaction time, distance between reader and tag and other RFID systems performances limit maximum speed of tram vehicle. Theoretically estimated relative speed between reader and tag at read distance of 0.8 m and 18 ms read latency for EPC Global system with 64 kbps bit rate is 167.7 kph [2]. So, for tram identification where vehicle speed does not exceed 50 km/h, RFID systems based on standard EPC Global Class1 Gen2 are adequate.
Communication could be accomplished in several ways. Because of high immediacy and large coverage, GSM/GPRS (Global System for Mobile communications/General Packet Radio Service) is suitable for connecting with remote traffic control centre. Added green or earlier phase start associated messages from traffic control centre to local controller could be sent via telecommunication network or local dedicated cable infrastructure. For direct tram -local controller communication, DSRC (Dedicated Short Range Communications) could be used due to extremely short time (milliseconds) in which transmitter and receiver recognize each other and exchange data (messages). Cheaper variant for tram-local controller communication is the use of ZigBee based private wireless network (International Standard IEEE 802.15.4). Line-of-sight range of ZigBee is from 100 m to a few km, depending on transmit power and antennas, but in presence of obstacles range could be only 10-15 m, so this technology should be tested in real environment.

Tag position should be sufficiently distant from the stop line, so that the throw in tram notification in adaptive traffic signal control algorithm has enough time to be processed. Rough assessment of this distance from stop line based on various tram speeds is from 80 m to 140 m from stop line. In order to minimize tram braking and optimize throughput of conflict flows additional data could be taken from IBIS i.e. tram speed and acceleration. In that case tram notification message from on board unit can contain predicted tram arrival time at stop line.

3. COMPONENTS, INSTALLATION AND TESTING

3.1. RFID reader

Stationary commercial available RFID reader HKRUR-3083 by HongKongRFID Ltd. was chosen due to declared manufacture specification: UHF 902-928 MHz, supports EPCglobal Class2/Gen 2 and ISO 18000-6B standards, RS232/RS485/Wiegand26/34 interfaces, max RF power output 30 dBm, antenna circular polarization, reading time – less than 6 ms for 64 bit ID, max. range read - 10 m and max range write - 4m (depends on tag), voltage power supply 9-12 V DC, mass 1 kg. With RFID reader manufacturer delivers API (Application Programming Interface)”Config” for configuring RFID reader and for writing in tags memory [13].

RFID reader with integrated antenna is encased in a plastic casing 24 cm x 24 cm x 3 cm, see Figure 2. Ingress Protection Rating by the IEC (International Electrotechnical Commissions) 6059 standard of this RFID reader is IP 54 (Limited protection against dust ingress / Protected against splash water from any direction). As shown on Figure 3, reader is mounted on steel console fixed on front section of tram undercarriage, just behind of traffic front bumper. This space is large enough (other metal parts of tram are spaced far enough from the reader), and reader is not directly exposed to various possible impact in real traffic environment. The mechanical mounting including preparation place for reader holder and wiring (power supply wire and communication line to the cabin) is rather fast, and take approximately two hours. Distance between mounted RFID reader and pavement is 40 cm.

Figure 2: RFID reader HKRUR-3083 (Hong Kong RFID)

Portable terminal device

On board unit with local computer is not yet fully developed. Instead this portable terminal device was made for testing purposes, figure 4. This device consists of a printed circuit board with microprocessor, memory, plastic case with LCD display and RS232 interface. Portable terminal initializes the RFID reader and gives the command to start the readout according to set up parameters which are written in terminal memory. During a test portable terminal records the last two codes from RFID reader and presents them on display.

Figure 4: Portable terminal device

3.2. Tags
Six different commercially available tags were obtained and tested. Tags were tested in regard to: range and angle of coverage, impact of water on needed output power for successful readout, and speed of readout (defines maximum permitted speed of vehicle).

Testing results of successful reading in regard to range and angle of coverage is shown in Table 1. RFID reader output power was set to 1 W. Testing angle of coverage means that tags were placed on fixed position, and reader was rotated around two axes. Of course there are declared radiation patterns for tags which presents range dependence based on angle in two planes, but we wanted empirically to find trusted angle of coverage regardless of plane. So in table 1. only one angle is presented.

Table 1. RFID range and angle of coverage

<table>
<thead>
<tr>
<th>TAG type</th>
<th>Manufacturer</th>
<th>Range declared</th>
<th>EPC code</th>
<th>Range (pow. 1W)</th>
<th>Angle of coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAG100</td>
<td>HKRFID</td>
<td>1m</td>
<td>1BC63000305FB63AC1F3681EC8A0B3</td>
<td>0,7m</td>
<td>60°</td>
</tr>
<tr>
<td>TAG-EX100</td>
<td>HKRFID</td>
<td>2m</td>
<td>ECE73000DB00FB63AC1F3841EC88004</td>
<td>1,8m</td>
<td>45°</td>
</tr>
<tr>
<td>HARSH 150W</td>
<td>PREMO Group</td>
<td>4m</td>
<td>D33C300030080A130A0A0A1235050001</td>
<td>4,2m</td>
<td>45°</td>
</tr>
<tr>
<td>MAX SQ-D</td>
<td>Omni-ID</td>
<td>4m</td>
<td>8FEF3400BBABBABBBBA0400010321C</td>
<td>5,2m</td>
<td>45°</td>
</tr>
<tr>
<td>DURA 1500</td>
<td>Omni-ID</td>
<td>8m</td>
<td>C5763400EA2A3A4A0000000000000001</td>
<td>9m</td>
<td>32°</td>
</tr>
<tr>
<td>DURA 3000</td>
<td>Omni-ID</td>
<td>15m</td>
<td>83EC30002010803840109001020001</td>
<td>17m</td>
<td>17°</td>
</tr>
</tbody>
</table>

Table 2. Needed RFID reader output power for successful reading in presence of water

<table>
<thead>
<tr>
<th>TAG type</th>
<th>Manufacturer</th>
<th>Water gauge</th>
<th>EPC code</th>
<th>Output power</th>
<th>Overall distance reader-tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAG100</td>
<td>HKRFID</td>
<td>10cm</td>
<td>-</td>
<td>30 dBm</td>
<td>40 cm</td>
</tr>
<tr>
<td>TAG-EX100</td>
<td>HKRFID</td>
<td>10cm</td>
<td>-</td>
<td>30 dBm</td>
<td>40 cm</td>
</tr>
<tr>
<td>HARSH 150W</td>
<td>PREMO Group</td>
<td>10cm</td>
<td>D33C300030080A130A0A0A1235050001</td>
<td>27 dBm</td>
<td>40 cm</td>
</tr>
<tr>
<td>MAX SQ-D</td>
<td>Omni-ID</td>
<td>10cm</td>
<td>8FEF3400BBABBABBBBA0400010321C</td>
<td>24 dBm</td>
<td>40 cm</td>
</tr>
<tr>
<td>DURA 1500</td>
<td>Omni-ID</td>
<td>10cm</td>
<td>C5763400EA2A3A4A0000000000000001</td>
<td>23 dBm</td>
<td>40 cm</td>
</tr>
<tr>
<td>DURA 3000</td>
<td>Omni-ID</td>
<td>10cm</td>
<td>83EC30002010803840109001020001</td>
<td>21 dBm</td>
<td>40 cm</td>
</tr>
</tbody>
</table>

Table 2. shows RFID reader needed output power in dBm in case of water presence for different tags. For this purpose plastic tank with 10 cm water gauge was placed over tags. Overall distance from RFID reader which is mounted on tram and tags on pavement is 40 cm. After that, reading accuracy was tested, but this time output power was set to maximum i.e. 30dBm. Table 3. shows these results. For each tag there were 100 trials of reading. Last testing was conducted with tram in motion, at the service polygon of ZET (Zagrebački električni tramvaj). Tags were placed on pavement and tram drives were repeated five times. Every result was the same.

Table 3. Accuracy of tags readings in presence of water

Table 4. Reading success of tags regard to velocity

Table 4. shows tags reading success regard to velocity. In table only last four EPC digit of successful reading tags is presented.
accuracy in presence of 10 cm water gauge. Very tight budget and short time limited number of available tags, and more detailed testing.

3.3. Tag installation and testing in real traffic conditions

Initial testing and following declared physical and RF specifications make tag MAX SQ-D by Omni-ID attractive to imbed in pavement, figure 5. Dimensions are 52.5 mm x 45 mm x 15 mm, mass is 24.5 g. Tag has Polypropylene encasement and has protection level IP68. Operating temperature -40 to +80 C. Shock and Vibration - MIL STD (US Military Standard) 810-F. Resistance to impact 25 kg from 1m. Can be mounted on metal surfaces. RF specifications of this tag are: EPC Class1 Gen2, frequency range from 860-930 MHz, IC Type chip Alien H3, and memory EPC - 96 bits/ User - 512 bits/ TID (Transponder ID)-64 bits. So, this tag was chosen & buried in pavement.

Figure 5: Tag MAX SQ-D (Omni-ID)

The test site in real traffic condition was in Savska Street, Zagreb. At this corridor standard pavement for traffic lanes is set i.e. concrete block with grid surface. The installation place of tag was 120 m before stop line of intersection Savska street-Hebrangova street, between tram rails. The installation of the tag includes several actions: pavement cutting with a circular saw, removing concrete from cut plan with a rivet gun, removing concrete debris, fixing the tag with nail or perhaps glue, and filling the space with fast setting concrete or other filler, Fig. 6. Hole dimension for tag is 10cmx10cmx4cm. The whole process takes approximately 15 minutes. But because works was interrupted with trams passing it took approximately 20 minutes. For other traffic i.e. vehicles with tires, this traffic lane should be under special traffic regulation for additional 20-30 min i.e. for time needed to filler become hard.

At this site five tram test drives were conducted. The reason for paucity test drives lies in the fact that at this point tram movement is slow (approx. 10 km/h), because tram station and intersection are just prior to this point. So, the special drives without passenger, and without stopping at the tram station were required with a view to achieve higher tram speeds. Every time RFID system was working properly i.e. readings of tag were successful at 10km/h, 15 km/h, 20 km/h, 25 km/h and 28 km/h. Higher speed was not possible to achieve at this site.

At the same location VECOM (VEhicle COMunication) system by Peek Traffic was installed. Moreover tag is placed just over the inductive loop of this system. Because the operation frequencies are different there is no RF interference between them. VECOM inductive loop is connected by a dedicated, buried cable to the VECOM roadside equipment which is placed in cabinet, 10 m away, with power supply and GPRS module for communication with EC TRACK server. So, the communication connection for the installed VECOM and for RFID system will be the same, except that the GPRS module of RFID identification system is located in tram.

Figure 6: Tag installation in pavement

Peek Traffic provided following information about communication connection and signal delay. GPRS message transfer time delay including data processing time was from 0.4 to 0.5 s. Reason for this long transfer time is complex signal path due to undeveloped telecommunication infrastructure of traffic control system in Zagreb. Signal path and processing include few links and nodes. First signal transmitted from GPRS module placed in cabinet at Hebrangova street to EC TRACK server in Selska street, after processing the message the control command was created. Than over public telecommunication network signal was transmitted to central control unit in Petrinjska street. After that through local control cable infrastructure signal is transmitted to local controller in Deželićeva street where control command was executed. Even though there is a significant delay of signal, system performance is not affected.

4. DISCUSSION

The appropriate commercial readers and tags could be found on the market, for installation proposed in this paper. In our case distance from RFID reader and tag is almost constant at 40 cm. So reader and tag are always in range, and all tested tags meet this condition. Testing the angle of coverage shows
that tags have different covering angles. Wider angle of coverage means that reader and tag are in range for a longer time period which results in higher possible speed of tram vehicle for successful tag readout.

Testing of tags in the presence of water, in fact simulates the presence of soggy/wet snow, and that for some tags in such conditions (in the experiment of 10 cm water gauge) there is still a "reserve" power. But, considering impact of real traffic environment on RFID reader, it should have higher IP protection level, for example IP 65 (Totally protected against dust ingress/ Protected against low pressure water jets from any direction. Limited ingress permitted,) and should be more robust in regard to vibrations. Regarding the performance of reading a tag depends on the speed, the theoretical values meet, but each RFID system must be tested in real conditions. Since we tested only up to 28 km/h in real conditions, further testing is required.

The advantage of RFID systems is identification at the exact position. Disadvantage compared to systems based on GNSS and communication technologies are needed works on traffic infrastructure. But in the case of setting the tag in the pavement, installation time is much shorter than for example the commercial system VECOM.

There are two advantages of RFID systems in which tag is placed in the pavement, compared to conventional systems where the tag is placed on the vehicle. The first is related to the cost of the overall system and maintenance. In fact, the number of required readers is equal to the number of tram cars, which is in larger urban areas, considerably less than the number of intersections (for each intersection should be from 2 to 4 readers), while the number of tags that are cheap (should be from 2 to 4 for an intersection) connected to the number of intersections. The second reason is related to the installation of equipment (RFID reader and tag). In order to install a RFID reader at a given site of the transport infrastructure it is necessary to prepare the infrastructure for installation, provide power supply and communication, while placing a tag on the transport infrastructure does not require any special preparation and can be performed in approximately 20 minutes.

During testing there was no real communication link from the tram to the local controller. The obstacles were administrative in their nature (permissions of the city government and other services) and of business nature (trade secret of the company that installs and maintains traffic control devices). However information provided by PeekTraffic shows that GSM/GPRS is usable technology for this kind of vehicle identification system.

5. CONCLUSION

Proposed vehicle identification based on RFID technology could be achieved by commercially available products. Potentially strengths related to common RFID installation scheme is smaller number of needed reader in overall control system, easier and quicker installation. At least this kind of system could be used to increase accuracy of system based on GNSS and communications.

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