New England University Transportation Center
77 Massachusetts Avenue, E40-279
Cambridge, MA 02139
utc.mit.edu

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Supplementary Vehicle Positioning to Connected Vehicles

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Principal Investigator:	Daiheng Ni	**Co-Principal Investigator:**	Jianqiang Wang
Title:	Associate Professor	**Title:**	Professor
University:	University of Massachusetts Amherst	**University:**	Tsinghua University
Email:	ni@engin.umass.edu	**Email:**	wjqlws@tsinghua.edu.cn
Phone:	413-545-5408	**Phone:**	(010) 6279-5774

Supplementary Vehicle Positioning to Connected Vehicles

Abstract: The U.S. Department of Transportation (DOT) has recently announced its decision to move on with Connected Vehicle Initiative. This requires future vehicles to be equipped with sensors and communication devices to enable vehicle-to-vehicle and vehicle-to-environment communication for improved safety. As large-scale applications of connected vehicles begin to roll out, a serious problem surfaces, i.e., vehicle positioning. Since many of these applications, such as cooperative collision warning and intersection safety supporting, assume accurate vehicle positioning in real time. Unfortunately, Global Positioning System (GPS) technology may not be adequate to serve the purpose. For example, conventional GPS receivers are accurate to 8-12 meters after removal of selective availability. Though differential GPS may narrow accuracy to 1-2 meters, it requires base stations and thus is only available at limited locations. In addition, GPS signals are frequently lost if line-of-sight is blocked and this is typically a problem in urban canyon. Therefore, there exists a present need for alternative vehicle position technology that supplements GPS at locations where position accuracy is critical but GPS service is inadequate or unavailable. This collaborative research proposes to investigate the alternatives and explore a viable solution with high reliability, low cost, and sufficient accuracy under all operational conditions.

1 The Problem

On February 3, 2014, The U.S. Department of Transportation's (DOT) officially announced its decision to move forward with vehicle-to-vehicle communication technology for light vehicles. A long list of innovative applications have been tested or under the way, in which real-time vehicle positioning serves as an underlying component. However, GPS-based vehicle positioning begins to show its limitations as connected vehicles are advancing toward real-world implementation and especially when the success of these applications depends heavily on the accuracy of vehicle positioning. These limitations include poor to no signal in certain areas especially urban canyon, and low positioning accuracy in a dynamic environment. Therefore, there exists a present need for alternative vehicle position technology that supplements GPS at locations where position accuracy is critical but GPS service is inadequate or unavailable.

2 The Proposed Solution

In this context, the approach of using radio sensors such as infrared, microwave, and radio frequency devices has received increasing attention. Capable of tracking moving objects, these devices can be mounted at roadside to transmit and receive data from vehicles passing in close proximity if they are equipped with transceivers. Due to its low cost and reasonable accuracy, radio-frequency identification (RFID) is promising as a supplement to GPS in connected vehicle applications at critical locations where GPS is unavailable or unreliable but the demand for real-time positioning is high.

RFID beacons are a series of passive RFID tags which are fastened on road surface containing position information, e.g., the distance to a reference point, lane number, and direction of travel. When a vehicle passes above an RFID beacon, the RFID reader and antenna carried by the vehicle activates the tag and reads in the position information. The layout of the RFID position system is illustrated in Figure 1 and hardware installation pictured in Figure 2. An example design of the format of position information is provided in Table 1.

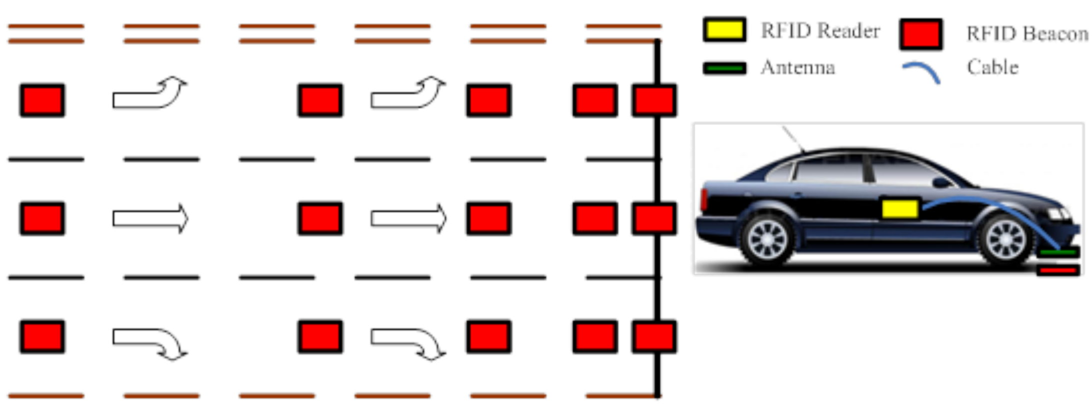

Figure 1 Layout of RFID beacons and reader

Figure 2 RFID tag, antenna, reader, and controller unit

Table 1 Definition of the data stored in RFID tags

Bit	Length	Value range	Note
0	1	0	Start Bit
1	1	0, 1	Stop Sign: 1: Yes ；0: No
2~9	8	0x00~0xFF	Distance to Stop sign on intersection, Unit: m
10~12	3	0x0~0x7	Lane No.: 0 ：Go Straight; 1: Turn Left
13~14	2	0~3	2: Turn Right; 3: U-Turn; 4: Go Straight and Turn Left; 5: Go Straight and Turn Right; 6: All Directions
15	1	0, 1	Orientation: 0: East; 1: South;

To facilitate the communication between the reader and the tags, an electronic control unit (ECU) was developed. As indicated in Figure 2, the ECU was used to control the reader by RS232 and to transfer data to other modules by CAN Bus. The connection of RFID reader, ECU and CAN Bus is shown in Figure 3. The ECU includes power module and CPU is based on Motorola 9s08DZ16 chip. The serial port transceiver is MAX232 and CAN transceiver is TJA1050.

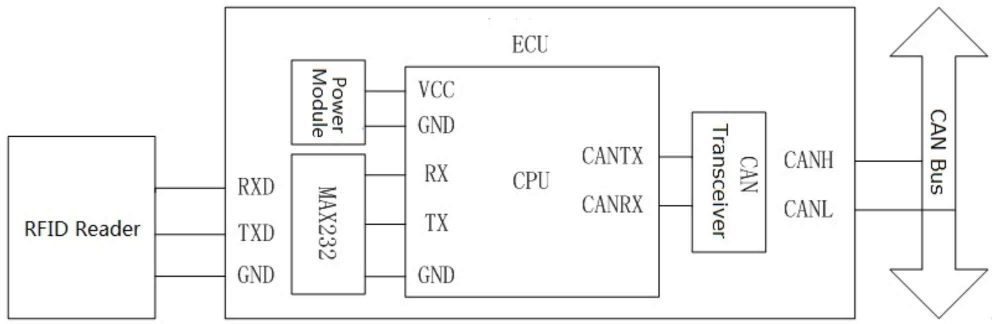

Figure 3 The connection of RFID reader and ECU

Since each RFID beacon contains static position information at a fixed location, a need arises for a vehicle in motion to acquire its accurate position in a continuous fashion in order to support connected vehicle applications. As such, a kinematics integration algorithm has been devised and added to the RFID positioning system, see Figure 4.

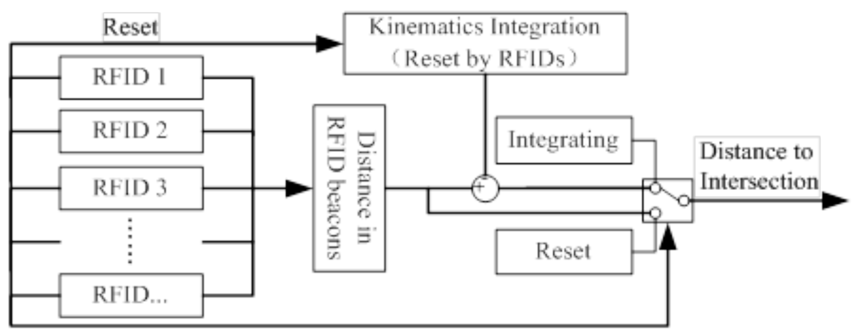

Figure 4 Kinematic integration algorithm

The algorithm calculates vehicle position as follows:

$$d_2 = d_{tag} + d_1$$
$$d_1 = \begin{cases} 0 & F_{tag} = 1 \\ \sum_k v_k \tau + \frac{1}{2} \sum_k a_k \tau^2 & F_{tag} = 0 \end{cases}$$

where, d_2 is current position; d_{tag} is the stored position obtained from RFID tag last time; d_1 is estimated driving distance according to speed integral; F_{tag} is a flag whose value is 1 (the system is able to read information from RFID tag) or 0 (otherwise); k is data sequence number, starting to count when the system fails to read the tag and reset to 0 when reading resumes; v and a are vehicle speed and acceleration respectively; τ is time elapsed since last successful reading from RFID tag.

3 The Findings

The accuracy of the RFID positioning system can be affected by RFID communication range and distance between tags. Since RFID only communicates within a few meters, reading from a tag only occurs when a vehicle moves over the tag which ensures accuracy. If the vehicle fails to obtain position updates from tags, its position has to be estimated. The longer the kinematics integration runs, the larger the estimation error. Therefore, it is necessary to avoid long gaps between tags to ensure accuracy.

Experimental verification based on radar was carried out where the experiment vehicle is equipped with radar, RFID reader and its antenna. The radar is installed on the vehicle's front fender guard. The radar wave beam is orient forward in the direction of travel. The antenna is installed below the fender guard, and the surface of the antenna senses the ground. The tags are installed on the test road, at the end of which is a fixed target to help radar measure distance. The radar features millimeter wave with frequency 76~77GHz, range up to 180 m, and resolution 0.7 m. The result shows that positions from radar, tags, and estimation match very well.

Experimental verification was also conducted using a photoelectric switch. The photoelectric switch consists of a transmitter which is fixed at roadside and a receiver which is fixed at the outside of the vehicle. Make sure that the transmitter is in the same cross section as a tag, while the receiver is also in the same cross section as the RFID antenna. As such, when the receiver moves with the vehicle and is aligned with the transmitter, both the RFID and the switch are triggered simultaneously. Starting from this instant, the on-board computer begins to estimate vehicle position using kinematics integration. Meanwhile, another source of position information is obtained from RFID tags. Test result showed that the error of position is about 5.4% in the first 30 m probably due to accelerating; when speed is relative stable, the errors drops to around 2.5%. It is also noticeable that, as the estimation goes on, the accumulated error increases. Further tests with lower maximum speed (e.g., 36 km/h) reduced the above errors to 3.1% and 1.8% respectively.

4 The Conclusion

This research proposed an RFID approach as a helpful alternative to positioning in connected vehicle applications where GPS is not available or of inferior quality. This approach installs RFID tags on road surface and an on-board tag reader in vehicles. When the reader passes over a tag, the reader can receive the position information stored in the tag. To fill gaps between tags, estimation has to be made based on the latest position update from tags. As such, a kinematics integration method is proposed to serve the purpose. When vehicles accelerate or decelerate, their speeds are changing, which affects the accuracy of the estimation method. Error of this nature can be diminished by applying the proposed calibration algorithm.

Road experiments were carried out to validate the RFID-based positioning approach. One type of experiments involves both radar and RFID reader on board. The radar is used to provide "true" positions of the test vehicle, against which estimates from RFID-based positioning are compared.

The result shows good match between the two sources of vehicle positions. The other experiment used a photoelectric switch to trigger the estimation of vehicle position based on the latest tag update. The results indicated that the error of position is about 5.4% during acceleration or deceleration process and around 2.5% when speed is relative stable. With the help of calibration algorithm, the errors can drop to 0.07 and 0.66 respectively.