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16. Abstract:

In this project, a high speed (up to 60mph) vehicle-mounted long range passive RFID (radio frequency identification) system was developed to locate highway reference markers by analyzing GPS and DMI data simultaneously. The system consists of two parts: hardware and software. The hardware includes an RFID reader, high-gain reader antenna and passive tag. The software includes a data display interface and a three-threads data acquisition system which can get the GPS, DMI and RFID data simultaneously. The read range of this system can reach up to 40 feet and locating resolution can be less than 13 feet. The life span of the whole system can be up to ten years and each of the RFID tag's cost is less than 2 dollars. An extra pavement attached version of passive patch antenna RFID tag was also developed, and it can be embedded in asphalt or concrete highway pavement. The read range of the whole system can be up to 6 feet.

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Application of RF Tags in Highway Reference Markers

by

Richard Liu and Yu Cai

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Project Number: 0-5536
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Performed in Cooperation with the
Texas Department of Transportation and Federal Highway Administration

by the

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Department of Electrical and Computer Engineering
University of Houston

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The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification or regulation.

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CHAPTER 1: INTRODUCTION

1.1 Background and overview

Radio Frequency Identification (RFID) is a new technology now widely used in different areas like supply chain management, inventory tracking, animal tracking, etc. It can also be used in a transportation system which normally requires high speed, high data rates and low cost and low maintenance fees. The most commonly seen RFID tag in the transportation system is the active EZ-Tag that is used to charge fees in tollways. (Fig 1-1)

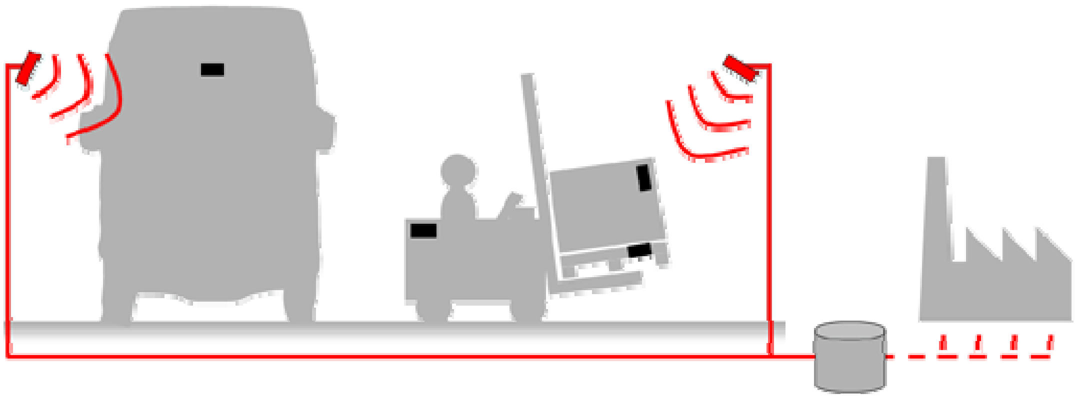


Fig 1-1 RFID Application in Transportation System and Supply Chain

Normally, RFID can be categorized in three different ways based on how the tags are powered up and activated:

Table 1-1 Cost of three different Tags

Power Generation	Cost	Read Range	Life Span
Active	~$10	~1mile	1-3 yrs
Battery Assisted / Semi Active	~$30	~100feet	3-5 yrs
Passive	<$1	15~30feet	unlimited

An active tag is a kind of tag that carries its own battery and works continuously regardless of whether the reader is nearby or not, until the battery runs down. The life span of an active tag is usually very short. The passive tag is a kind of tag that doesn't carry its own power source or battery. The energy that is used to power up the tag is from radiation of the reader antenna. Its merit is that it is inexpensive and has a low maintenance cost and long life span. But the read range of the passive tag is much shorter than the active one. The battery-assisted tag is an intermediate version between the active tag and passive tag. The power radiated from the reader side is only used for intriguing a switch in the battery-assisted tag. When the switch is on, a battery in the tag will start to provide power for the whole semi-active tag. After data is sent back to the reader, the semi-active tag will automatically switch off its power, and the battery will go into sleep mode. By using it this way, the semi-active tag can decrease the power consumption of the on-board battery as much as possible and make the life span longer while not sacrificing the read range too much. (Table 1-1, Fig 1-2)

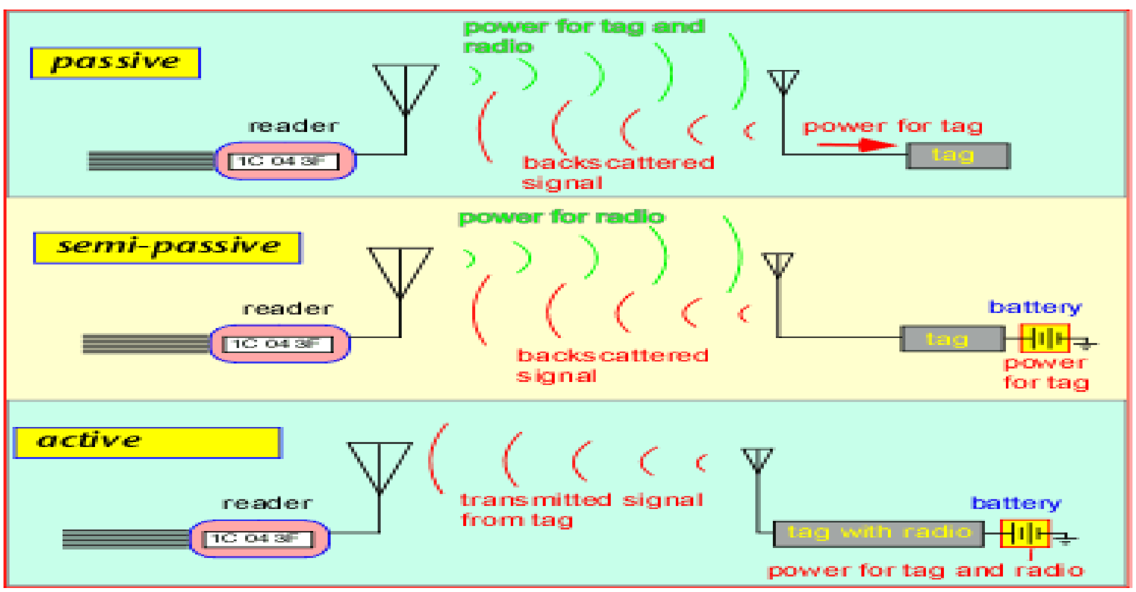


Fig 1-2 Principles of Active, Semi-passive and Passive RFID

In our project, what we are concerned with most is the life span, cost and maintenance fees. If the read range is up to 18 feet, then the tag can be considerable. Therefore, the passive tag proved to be our favorite.

In this Project 0-5536, the Subsurface Sensing Laboratory of the University of Houston developed a passive RFID system that can be used to locate positions of reference markers along highways in high speed (60mph) conditions. This system is a passive system which means that in the tag side there is no battery needed and no maintenance needed for ten years. The power that the tag needs is totally coming from power radiated from the reader side. It's like a reader illuminating the tags by sending a microwave to it. Whenever the tags are illuminated, they will be activated and then send the signal and information inside the tags back to the reader.

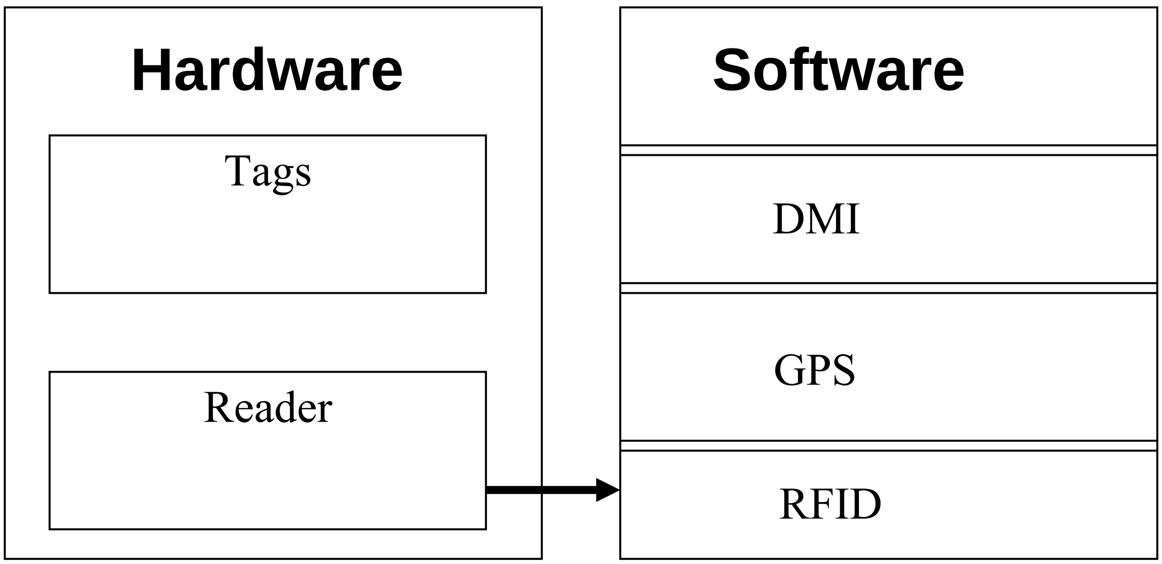


Fig 1-3 Highway Reference Marker Locating RFID System

The primary reason for locating reference markers is because the reference markers are easily moved or shifted from their original positions due to man-made reasons such as construction, or seismic reasons such as earthquakes, hurricanes, etc. In addition, there is not a good way to monitor it in a highly efficient way without a high cost of maintenance, labor and fees.

The long-range passive RFID system makes high efficient maintenance of the reference marker possible.

A block diagram of the system is shown in Fig. 1-3. The data acquired through the reader is sent to the software system to deal with. More details will be in the following chapters.

CHAPTER 2: HARDWARE SYSTEM

The RFID hardware system consists of two parts: reader side and tag side. The reader side is a complicated power consuming RF transceiver with two high-gain Yagi antennas. The high-gain antenna is a kind of antenna with high directivity and can provide high precision locating resolution. The tag side is relatively simple because it consists of one printed meander dipole antenna and a passive RFID chip. The main purpose of the passive RFID is to save useful information inside the on-chip memory and send it to the reader by simply absorbing a small piece of energy radiating from the reader.

2.1 Reader

The reader is a 915MHz transceiver that supports multi-protocol like EPCglobal Class1 Gen 2 (North America Standard), TAGIDU/ATA5590 (ATMEL RFID protocol), ISO 18000-6B, etc. In our project, we are using TAGIDU/ATA5590 protocol which is developed by ATMEL by using ASK (Amplitude Shift Key) in downlink transmission and PSK (Phase Shift Key) in uplink transmission. It also has an anti-collision mechanism that can support a multi-tag environment.

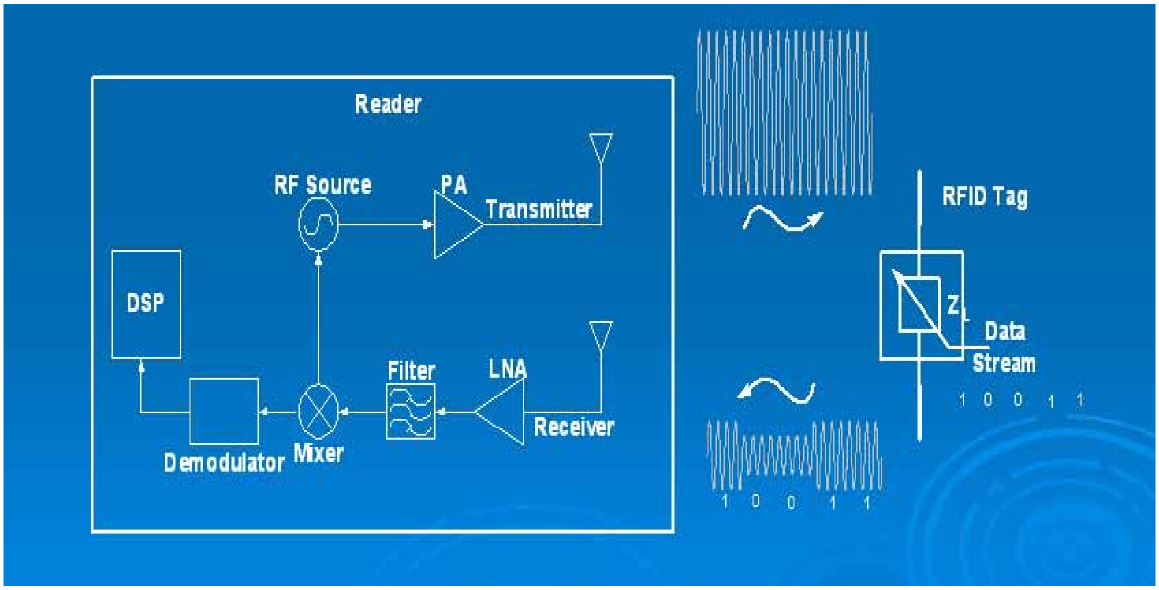


Figure 2-1 Block Diagram of Backscattering RFID System

The most important reason that we use this protocol is because the ATA5590 chip can support the longest read range among all passive RFID chip manufacturers by far. With carefully designed printed antenna, the chip can support a read range of up to 40 feet when the power in the reader side is 4W EIRP. ATA5590 is a passive RFID chip using a backscatter mechanism to transmit and receive data. Backscattering modulation is currently the mainstream modulation scheme in the Passive RFID industry and has been adopted as the industry standard. In a backscattering modulation RFID system, the reader sends a signal with constant amplitude, the tag switches its load on and off in terms of its information saved inside the chip and modifys the radar cross section of the antenna. The reflected signal amplitude will be modulated with the information due to radar cross section variation. (Fig 2-1)

For long range application, high-gain antenna selection in the reader side is very important. The good high gain antenna can provide both high locating resolution and long read range. In our application, two high gain (8.5dBi) Yagi antenna are selected and mounted in front of the van. The transceiver signal is transmitted via long coaxial cable through the antenna to the transceiver inside the van. (Fig 2-2)

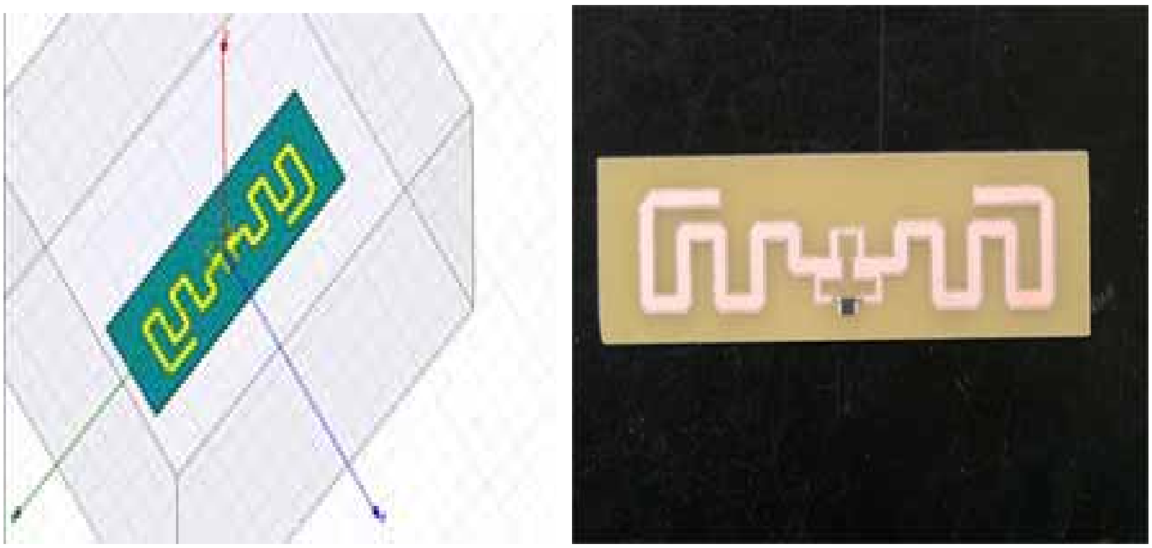
a) b)

Fig 2-2 Hardware System: a) Transceiver, b)Tx/Rx Antenna

2.2 Tag

A major concern when we developed the passive RFID tag was cost. The passive tag consists of an RFID chip and printed antenna. The cost mainly comes from the chip rather than the antenna because normally the printed antenna is fabricated on low cost FR4 board. The chip we selected here is Atmel ATA5590 UHF RFID IC. The cost of each chip is 75 cents. The chip itself has a large on-chip memory that can read/write repetitively. The power consumption of the chip is only $12\mu W$.

The tag antenna is a meander dipole antenna whose size is only 4×1.5 inches. The meander dipole is a modified version of the dipole antenna but with smaller overall size. The gain is around 3.5dBi based on an HFSS simulation result. (Fig 2-3)



a) b)

Fig 2-3 Meander Dipole Antenna for Passive RFID Tag: a) HFSS Simulation Model; b) RFID Prototype

The meander dipole is fabricated on the top of a 62.5mil FR4 board which is high-temperature resistant and hard. It is also very cheap and easily fabricated in huge amounts.

CHAPTER 3: SOFTWARE SYSTEM

3.1 User Interface

The RFID software system is developed on the Microsoft VC++ 6.0 platform. It is a multi-threads system which can read data from three different channels simultaneously and show them on the user interface.

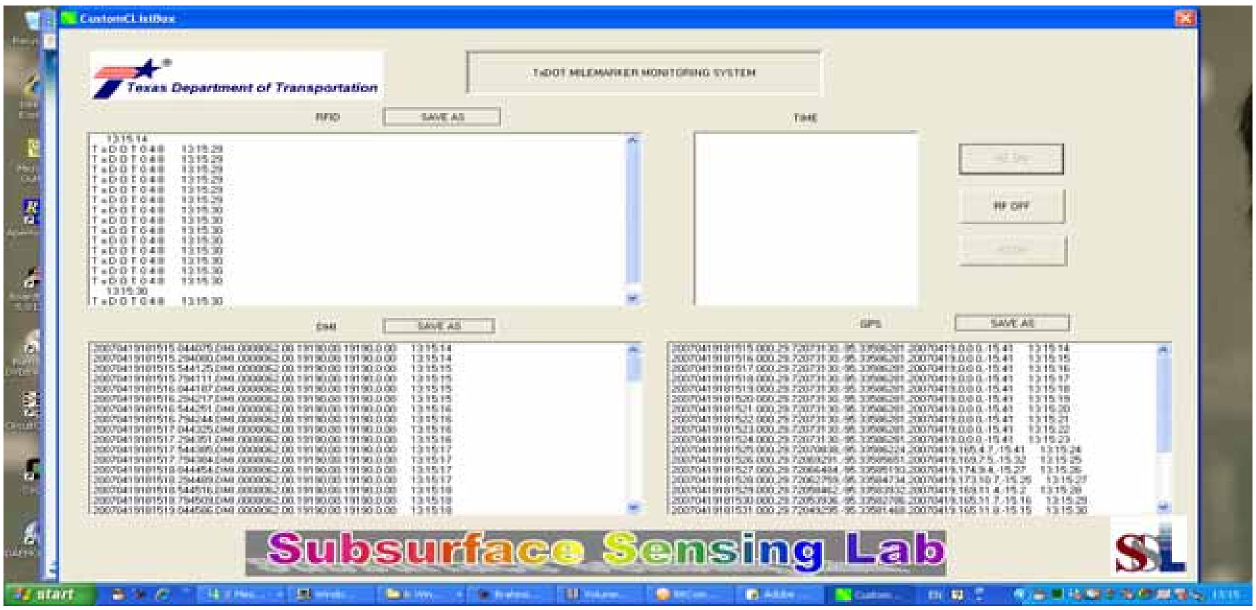


Fig 3-1 Highway Reference Marker Software Interface

3.2 Multi task data acqusition system

The software system of this project is a multi-task system. Thus it needs an operating system of the host control computer to support the multi-task mechanism. The MS VC++ 6.0 support, so-called multi-threads mechanism, allows us to get three different data through three different channels simultaneously.

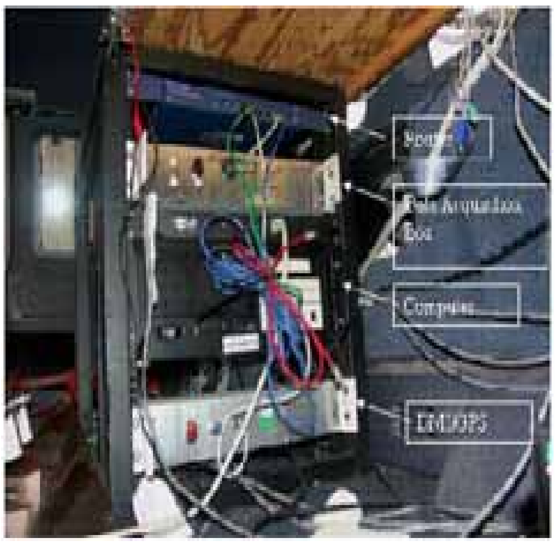
3.2.1 RFID Data Acquisition Thread

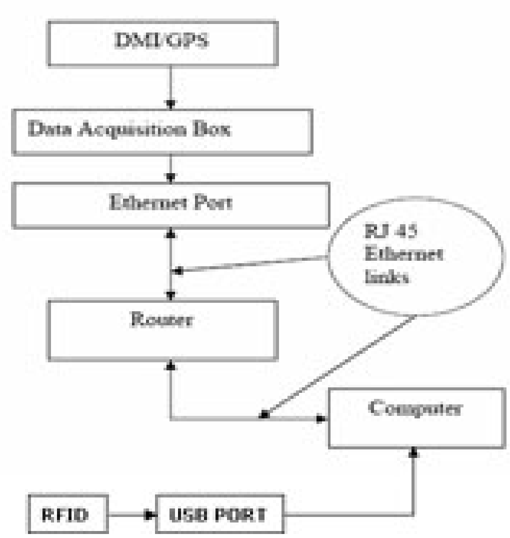
RFID data is sent through an RS-485 wire from the reader to an RS-485/USB converter. Through this converter, the data can be read through the USB port by an RFID data acquisition thread. Actually, the RS-485/USB converter is also a virtual serial port converter which can make the USB port look like a conventional serial port by a Windows application program.

When the thread is read the data from the USB, it is just like reading from an RS-232 serial port. The way of reading is similar to just reading from a file.

3.2.2 GPS Data Acquisition Thread

GPS data is collected by a data acquisition box inside the van and the data acquisition box broadcasting the GPS data via Ethernet cable in UDP protocol. The port number it used to broadcast is 4005.





a) b)

Fig 3-2 a) DMI/GPS Data Acquisition Box; b) Block Diagram of Local Access Network Inside the Van.

3.2.2 DMI Data Acquisition Thread

The DMI data acquisition process is similar to the GPS data acquisition method. However the port number it uses is 4008 rather than 4005.

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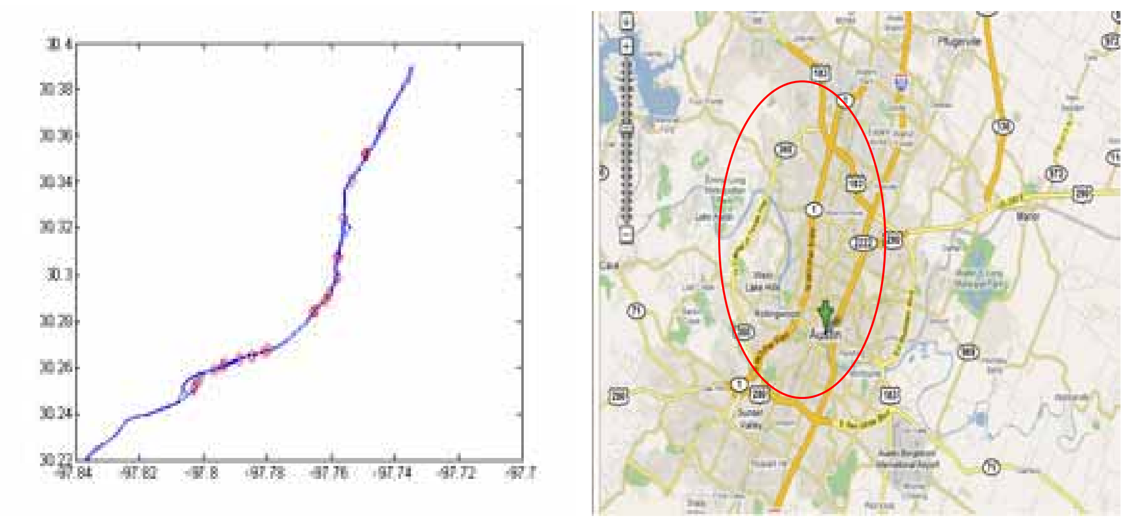
CHAPTER 4: FIELD TEST RESULTS

4.1 Overview

A field test is performed to test the system's performance and robustness in actual conditions and environment. The parameters include the read range, locating resolution, reading rate vs. speed, etc.. The test site is on the Austin Loop 1 highway.

It is important to note that the purpose of developing this system is for locating. Therefore, the most important parameter of the whole system is locating resolution. In this chapter, how to measure and test the locating resolution, the relationship between this parameter and driving speed and timer resolution will also be discussed in detail.



a) b)

Fig 4-1 a) GPS Data Collected on the Road (blue line) and Location of Tags (red marker); b) Google Maps of the Test Sites.

To get the farthest reading range and better performance of the whole system, the tag should be mounted correctly (Fig. 4-2). Otherwise the system will not be able to read the information inside the tag due to a polarization mismatch between the reader antenna and the tag antenna. The height of the tag should be around 2.65 feet above the surface of the pavement.

Fig 4-2 Marker Mounted with Yag

The test is like playing a hiding game between the vehicle mounted with the RFID reader and 25 tags mounted along Loop 1. The vehicle mounted with the reader drives along Loop 1 and locates the position of the tag by acquiring RFID data and comparing them with concurrent GPS/DMI data. Then the exact position of the tags can be decided.

Fig 4-3 Highway Reference Marker Under Test

4.2 Locating Algorithm

Locating is accomplished by software. By getting the GPS and DMI data simultaneously, RFID data can be compared with the GPS and DMI data in terms of a common synchronized clock. Then the location of the reference marker can be decided by the GPS data combined with the DMI data. (Fig 4-4)

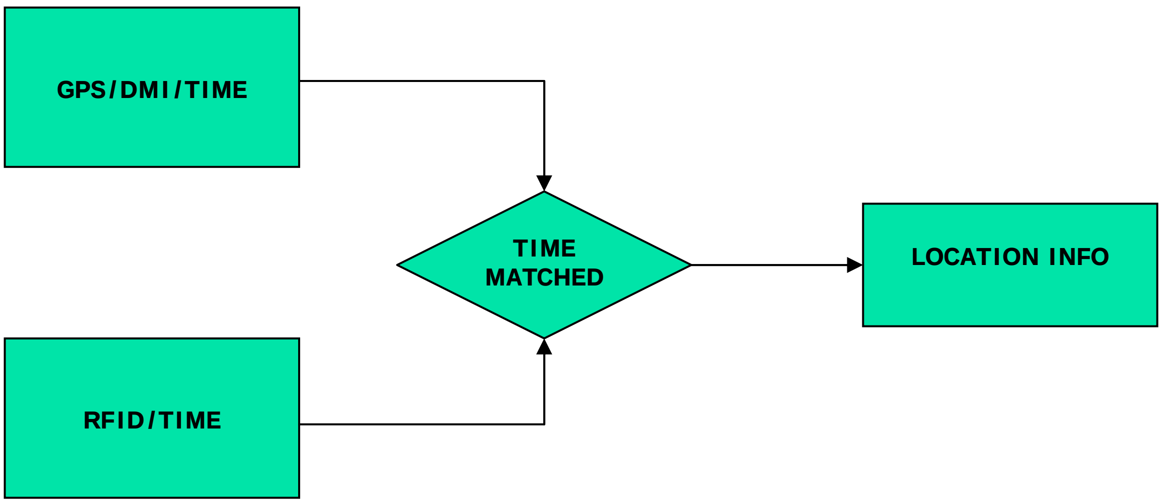


Fig 4-4 Block Diagram of Locating Algorithm

4.3 Locating Resolution

Locating resolution is decided by software timer resolution, DMI resolution, GPS resolution and driving speed.

Table 4-1 lists time resolution for each different data channel.

Table 4-1 Time Resolution

Max software timer resolution	Time resolution in the Demo day	GPS	DMI	Max RFID READING (depends on distance and driving speed)
10ms	1s	1s	250ms	20~80ms

The software timer can be easily adjusted by the developer. The maximum timer resolution is 10ms. In the demo day, we use a 1s timer to do the demo, so the maximum resolution is decided by the GPS resolution. The DMI data was not taken into account for the final locating process.

The system combining DMI/GPS data needs the software timer to be adjusted to 10ms, and the overall locating resolution will be decided by DMI.

Here are two examples showing how the timer resolution and GPS/DMI resolution influence the locating resolution of the whole system.

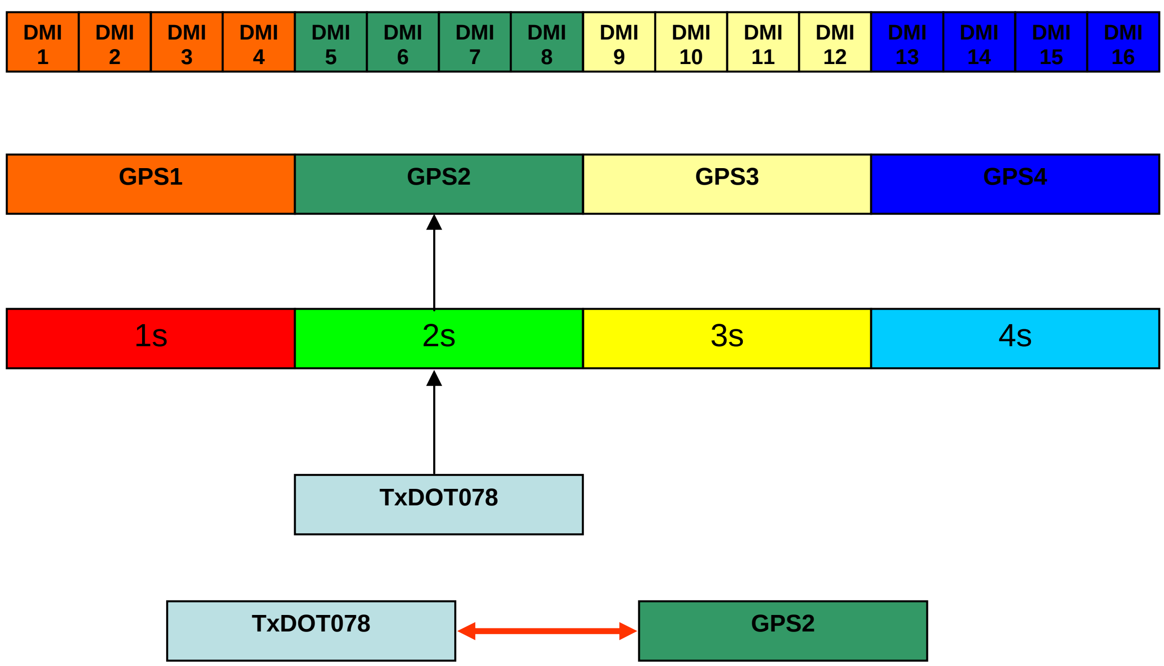


Fig 4-5 Locating Example 1 (timer resolution = 1s)

Example 1 shows that when the timer resolution is 1s, the whole system locating resolution is only decided by the GPS resolution under that driving speed. In this situation, the DMI data will not essentially contribute to locating. (Fig 4-5)

Because the RFID data updated rate totally depends on timer resolution, so the timer resolution is the pivotal factor in the whole system. When the timer resolution is the same as the GPS resolution but larger than the DMI resolution, the locating resolution would be decided by the GPS resolution as shown in Example 1.

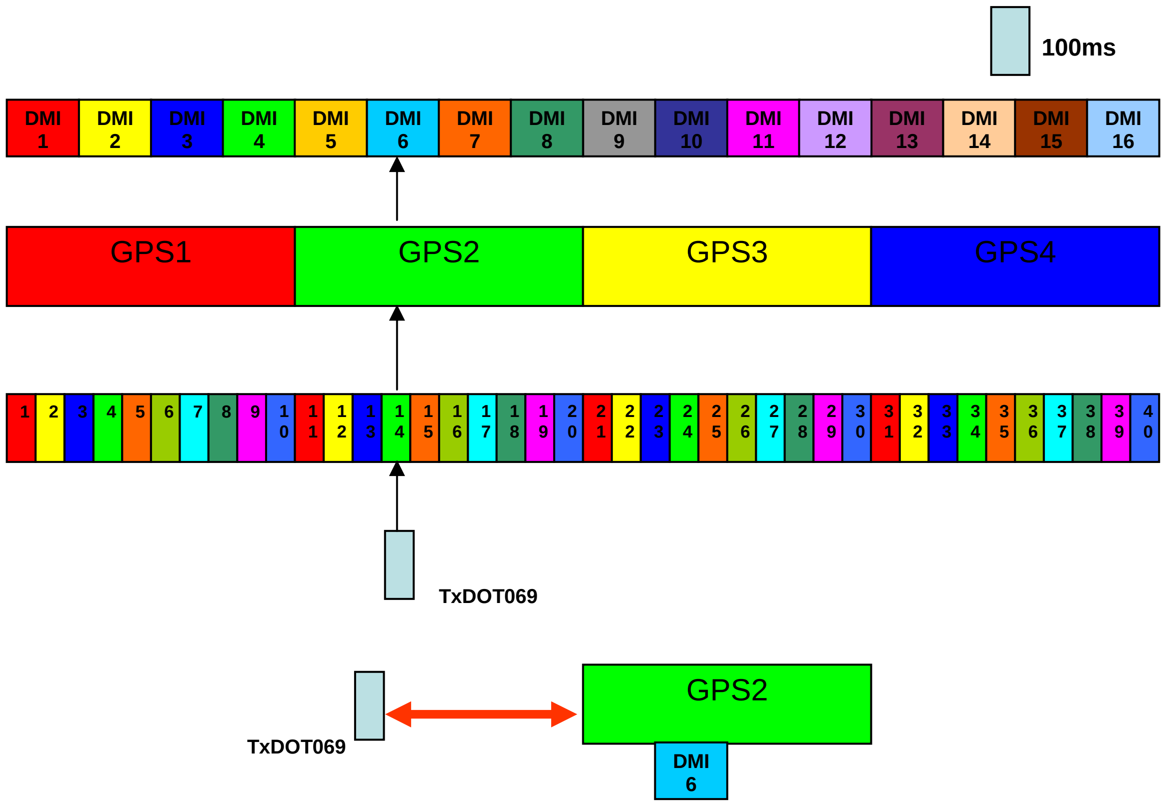


Fig 4-6 Locating Example 2 (timer resolution = 100ms)

Example 2 shows that when the timer resolution is 100ms, the location of the tag can be decided by both the GPS data and DMI data. The final locating resolution is decided by DMI time resolution (250ms) and driving speed. (Fig 4-6).

When the RFID resolution (timer resolution) is smaller than the DMI resolution, the overall locating resolution would be decided by the DMI resolution rather than GPS because the GPS is four times rougher than the DMI resolution.

Based on the previous two samples, it is noticed that the locating resolution is highly dependent on the driving speed of the vehicle. The relationship between locating resolution and speed is shown in Table 4-2.

Table 4-2 Locating Resolution (feet) VS. Speed (mph)

	Time Resolution		
Speed (mph)	**1s**	**10ms**	**250ms**
10	**13.32**	**0.1332**	**3.3**
20	**26.7**	**0.267**	**6.675**
30	**40**	**0.4**	**10**
40	**53**	**0.53**	**13.25**
50	**66.67**	**0.67**	**16.75**
60	**80**	**0.8**	**20**
70	**93.33**	**0.933**	**23.3**

Table 4-3 Locating Resolution Conclusion

Time Resolution	**Locating Reference**	**Locating Resolution (50mph case)**
>1s	**TOO ROUGH**	**>66.67’**
250ms< = & <=1s	**GPS data only**	**66.67’**
10ms<&<250ms	**GPS/DMI COMBINED**	**16.75’**
<10ms	**Out of timer resolution**	**16.75’**

Tables 4-2 and 4-3 show the maximum locating resolution is decided by DMI resolution, timer resolution and driving speed together. With driving speed increasing, the locating resolution is decreasing. The higher the timer resolution is, the higher the locating resolution is. The result from the table is similar to the result based on Examples 1 and 2 (Fig 4-5, 4-6).

4.3.1 Test Results

The measurement data acquired in the Loop 1 test field on the demo day is shown in Table 4-4. The data measured by the RFID system are compared with the standard data provided by TxDOT. The error is also calculated and shown in the table and in Fig 4-7.

Table 4-4 Locating Result Based On GPS Data

(1s resolution/DMI data is not used in 1s case)

Tag ID#	GPS	Measured GPS	Error
34	**N 30 15.062** **W97 48.157**	**N30 15.0540** **W97 48.1631**	**N 30 -0.008** **W 97 0.0061**
13	**N 30 15.216** **W 97 48.101**	**N 30 15.2028** **W 97 48.1052**	**N 30 -0.0132** **W 97 0.0042**
41	**N 30 15.300** **W 97 48.065**	**N 30 15.2900** **W 97 48.0713**	**N 30 -0.01** **W 97 0.0063**
40	**N 30 15.545** **W 97 47.755**	**N 30 15.5362** **W 97 47.7746**	**N 30 -0.0088** **W 97 0.0196**
33	**N 30 15.624** **W 97 47.611**	**N 30 15.6193** **W 97 47.6272**	**N 30 -0.0047** **W 97 0.0162**
22	**N 30 15.794** **W 97 47.307**	**N 30 15.7923** **W97 47.3129**	**N 30 -0.0017** **W 97 0.0059**
14	**N 30 15.902** **W 97 47.048**	**N 30 15.9023** **W 97 47.0535**	**N 30 0.0003** **W 97 0.0055**
6	**N 30 15.995** **W 97 46.825**	**N 30 15.9916** **W 97 46.8313**	**N 30 -0.0034** **W 97 0.0063**
39	**N 30 17.076** **W 97 45.871**	**N 30 17.0760** **W97 45.8758**	**N 30 0** **W 97 0.0048**

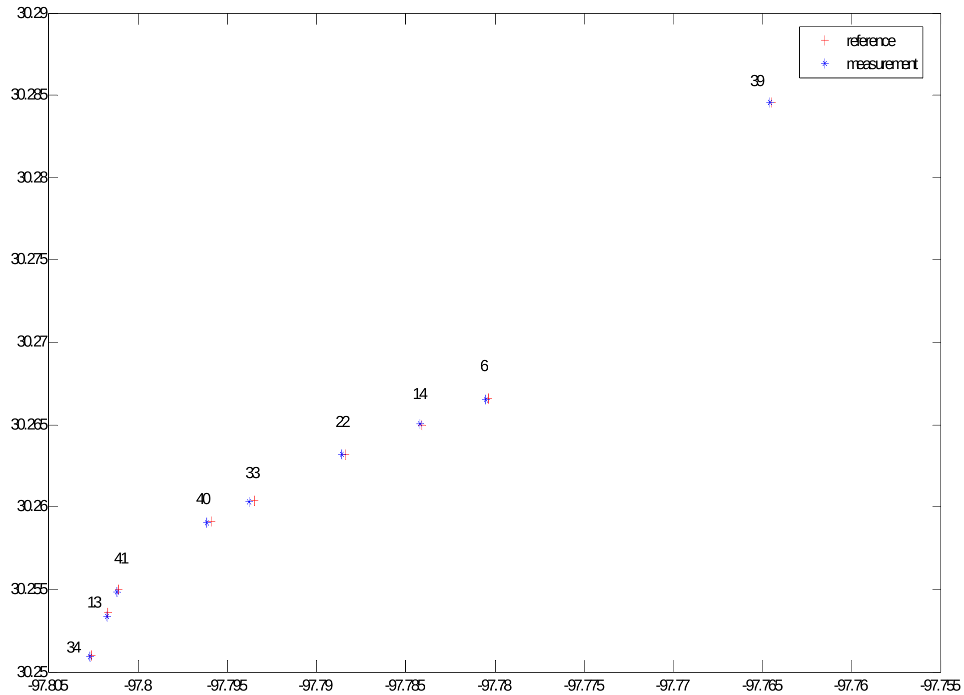


Fig 4-7 GPS Measurement Data vs. Reference Data

From the previous results, the locating is very precise compared with reference GPS data. This means the locating resolution (<0.019 degree) is high enough to fulfill a practical situation requirement.

CONCLUSIONS AND SUGGESTIONS

The highway reference marker locating system based on a long-range RFID system is developed for demonstration on Loop 1, Austin, Texas. The result is excellent. The system can work at high speeds (more than 55mph) and in long range (40 feet) situations. The locating resolution is as high as 16.75’.

The whole system consists of hardware parts and software parts. The cost of the whole system is around US $5,000 and the maintenance fee for the system is low because the lifespan of passive tags is normally greater than five years.

The reader system can be also used in another version of RFID which is put on the surface of highway pavement. This makes it a good candidate for future applications. (Fig 5-1).

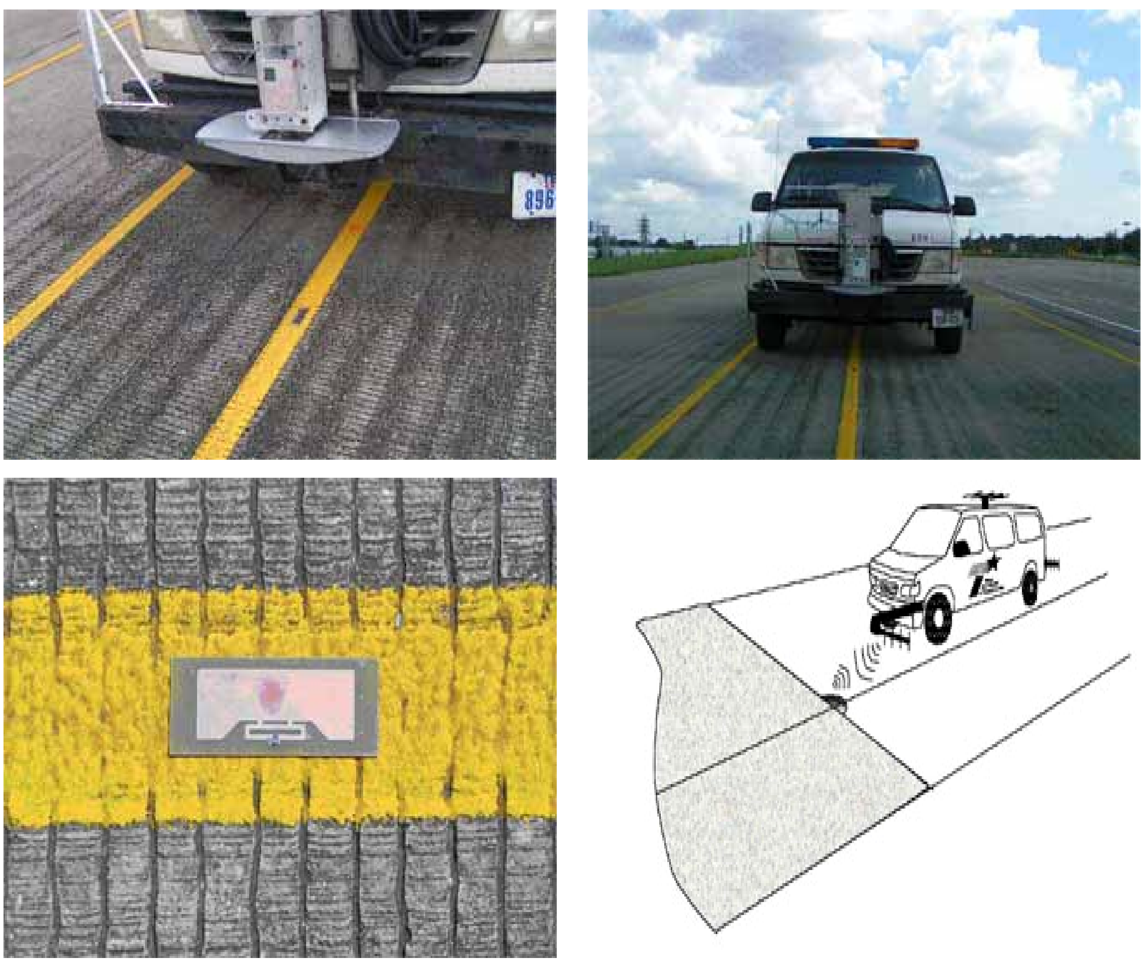


Fig 5-1 RFID For Highway Surface Mount Application

REFERENCES:

ATA5590 Datasheet (2007). http://www.atmel.com/dyn/resources/prod_documents/doc4817.pdf.

User Guide: Long-range UHF RFID Demo Kit for IDIC® TAGIDU™ ATA5590, http://www.atmel.com/dyn/resources/prod_documents/doc4910.pdf.

Atmel Corporation, Atmel Application Notes: ATA5590 Tag Antenna Matching, http://www.atmel.com/dyn/resources/prod_documents/doc4843.pdf.

Atmel's High-performance UHF IDIC Demo Kit Supports Long-range RFID Applications, http://www.atmel.com/dyn/corporate/view_detail.asp?FileName=ATA5590_12_14.html.

Jari-Pascal Curty, Michel Declercq, Catherine Dehollain and Norbert Joehl, Design and Optimization of Passive UHF RFID Systems, Springer Verlag, 1st edition, 2006.

Madhuri Eunni, Mutharasu Sivakumar and Daniel D.Deavours, A Novel Planar Microstrip Antenna Design for UHF RFID, www.ittc.ku.edu/~deavours/pubs/jsci07.pdf.

Madhuri Bharadwaj Eunni, A Novel Planar Microstrip Antenna Design for UHF RFID, University of Kansas, MS Thesis, 2004.

Constantine A. Balanis, Antenna Theory: Analysis and Design, 3rd Edition, Wiley-Interscience, 2005.

EPC Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for Communications at 860MHz – 960MHz, Version 1.0.9, January, 2005.

Diester Electronic, UDL500 UDK1 Protocol V1.10, V30/08/05.