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Architecture Design of the Vehicle Tracking System based on RFID

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Abstract

Vehicle tracking plays more important roles in modern transportation and logistics operation. This paper deals with a new approach to track vehicles based on RFID (Radio Frequency Identification) technology. The vehicle tracking system is designed overallly supported by Axiomatic Design theory. The basic steps of vehicle tracking based on RFID are developed and a six-layered architecture for the vehicle tracking system integrating databases, RFID tags, RFID readers, data centers, networks and user interface is presented, where the positions of vehicles are attained directly by compared the RFID readers collecting vehicle RFID tags their position information in the database. It is shown that this vehicle tracking method uses RFID more fully, the architecture with clear levels, adapts to the future technical and practical requirements, and can help fuse more complicated applications like intelligent charging and cargo tracking.

Keywords: *vehicle tracking, RFID, architecture, tracking system, axiomatic design*

1. Introduction

Vehicle Tracking (VT) is the main work of intelligent transporting system and modern logistics and plays more and more important roles, where the key is tracking location of vehicles. Several types of vehicle tracking methods and vehicle tracking service systems have been developed [1]. Almomani et al. [1] created a ubiquitous GPS (Global Positioning System) vehicle tracking and management system, where the General Packet Radio Service (GPRS), Global System for Mobile Communication (GSM), the Internet or the World Wide Web and GPS were mainly used.Chen [2] developed a 3G (GPRS、GPS、GIS) vehicle tracing service system. Wang et al. presented a vehicle tracking system based on wireless sensor network with a four-layered architecture [3]. It is obvious that modern vehicle tracking systems commonly use GPS technology for locating the vehicle.

Because of the intelligent requirements of the modern society and the effects of globalization, besides the safety problem for vehicle tracking, other more intelligent applications are expected based on it, such as intelligent charging, anti-theft tracking, cargo tracking, and so on. At the time the Internet of Things (IOT) are proposed, too. All the applications above require vehicle tracking systems have reliable identification functions. One of technologies that meet the demands is RFID [4]. It offers advantages of non-touch identification, long-distance communication, working in a variety of harsh environments and that can read hundreds tags at a time. These features have been attracting more and more governments and organizations to invest it.Nowadays RFID has been applying to gate guarding systems, inventory management, goods tracking [4-5] and intelligent speed test [6]. However, it appears that, among all these applications, RFID mainly acts as an identification and very limited works have been carried out to study more complicated applications.

Thus, this paper aims to the methodology of tracking vehicle based on RFID. Axiomatic Design (AD) is introduced to help design the tracking system. An architecture of the vehicle tracking system based on RFID and the process of tracking vehicle are presented.The rest of this paper is arranged as follows.The first section introduces the Axiomatic Design theory. The second demonstrates the architecture design process of tracking vehicle system based RFID. An application case constructed according to the architecture is presented in the last section.

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2. Axiomatic Design Theory

Axiomatic Design (AD) theory, presented by Professor Nam Pyo Suh of MIT [7], provides a standardized logic framework for general design. It defines the design world as four domains: the customer domain, the functional domain, the physical domain, and the process domain, and thinks designing is a top-down zig-zagging process of decomposition and translation between the close two domains. The customer domain describes the needs or benefits that the customers or end users are looking for. In the functional domain, the customer needs are interpreted in terms of functional requirements (FRs) and constraints (Cs). Then solutions, design parameters (DPs) are created and selected in order to satisfy the specified FRs, in the physical domain. Finally, to produce the product specified in terms of DPs, we develop a process that is characterized by process variables (PVs) in the process domain [8].For each mapping between two adjacent domains, the left domain represents "what we want to achieve," while the right one represents the design solution of "how we propose to achieve it, where the design matrix (DM) equation is introduced to describe this process and the mapping just like:

$$\{FRs\} = [A]\{DPs\}, \tag{1}$$

here *A* is a DM.Three types of DMs are generally involved in Axiomatic Design, as shown in Figure 1, where it is supposed there are three FRs and DPs, *X* or 0 in a cell indicates whether the columns DP affects the rows FR or not. It is important to satisfy the independence axiom firstly when applying AD, which requires keeping FRs independent, namely avoiding functional coupling.Thus only the design whose DM is diagonal or triangular like Figure 1 (a) or (b) satisfies the independence axiom. Axiomatic Design now has been used to design physical products , software development and management programming , and so on [9].

$$\begin{array}{c} \\ FR1 \\ FR2 \\ FR3 \end{array}\begin{array}{c} \begin{array}{ccc} DP1 & DP2 & DP3 \end{array} \\ \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \\ \text{(a)} \end{array} \quad \begin{array}{c} \\ FR1 \\ FR2 \\ FR3 \end{array}\begin{array}{c} \begin{array}{ccc} DP1 & DP2 & DP3 \end{array} \\ \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & X & X \end{bmatrix} \\ \text{(b)} \end{array} \quad \begin{array}{c} \\ FR1 \\ FR2 \\ FR3 \end{array}\begin{array}{c} \begin{array}{ccc} DP1 & DP2 & DP3 \end{array} \\ \begin{bmatrix} X & 0 & 0 \\ 0 & X & X \\ 0 & X & X \end{bmatrix} \\ \text{(c)} \end{array}$$

Figure 1. Three Kinds of Design Matrices

3. Axiomatic Design of the Vehicle Tracking System

3.1. Axiomatic Design Process

According to the analysis above, besides tracking a vehicle, a vehicle tracking system now should meet other requirements, some of which like anti-theft tracking are generated by the internet of things. These other needs are actually applications based on obtaining the position of a vehicle, here defined as extended requirements which can be integrated into the basic requirement, tracking vehicles, to satisfy the independence axiom. Thus, in the hightest level, the FR, FR_1 is tracking vehicles, the corresponding DP, DP_1 is the vehicle tracking system based RFID.

To track a vehicle, it is essential to get its realtime position information, and display it on the map, as well record it for more further applications. Amid, the position information of a vehicle is not handle directly by collecting modules of the position information but generally transferred to top programs. Therefore FR_1 can be decomposed into FR_{11} (collecting position information of vehicles), FR_{12} (transforming the position information), FR_{13} (transferring the position information), and FR_{14} (handling the position information). DP_1 is defined as DP_{11} (information gathering module), DP_{12} (transformation module), DP_{13} (transfer networks), DP_{14} (data center including database). And then the design equation relates to these FRs and DPs can be expressed by:

$$\begin{bmatrix} FR_{11} \\ FR_{12} \\ FR_{13} \\ FR_{14} \end{bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 \\ X & X & 0 & 0 \\ 0 & X & X & 0 \\ 0 & X & 0 & X \end{bmatrix} \begin{bmatrix} DP_{11} \\ DP_{12} \\ DP_{13} \\ DP_{14} \end{bmatrix}. \tag{2}$$

Equation 2 indicates the decomposition satisfies the independence axiom, but FR_{11} to FR_{14} are all not leaf parameters.So more detailed decomposition needed to satisfy design requirements.

FR_{11}, according to vehicles identifiers, mainly collects their position information in a certain form at different time by responding the collecting devices, which has sub-functions including FR_{111} (identifying vehicles), FR_{112} (responding) and FR_{113} (timing). There are many ways to identify a vehicle such as RFID tags, bar codes and common numbers. Here we chose RFID tags because of more advantages mentioned above over other ways. Since RFID tags depend on RFID readers, when a reader reads a tag, it means responding between the tag and reader takes place. Accordingly the position of responding is supposed to be that of the vehicle, no matter it is moving. This makes it available to gather the position of a vehicle by the location of the RFID reader just reading its tag, on condition that the reader is deployed in advance at spots where vehicles are required to scanned, for example, the sides of roads, and its location is saved in database.Thus the whole design solutions are described as follows.

$$\begin{bmatrix} FR_{111} \\ FR_{112} \\ FR_{113} \end{bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{bmatrix} DP_{111} \\ DP_{112} \\ DP_{113} \end{bmatrix} \quad (3)$$

Here, DP_{111} is RFID tag, DP_{112} is RFID reader, DP_{113} represents controller which adds a timer to the position information. It is obvious that RFID technology plays roles of both identifier and positioning in our solutions.

FR_{12} inputs the position information from DP_{112}, then checks and turns it into a valid form to send by DP_{13}, at the same time outputs control information from the data center. It has the following sub-functions: FR_{121} = inputting position information, FR_{122} = data filtering, FR_{123} = formatting, which are maintained by the parts of DP_{12}, DP_{121} (connection interface), DP_{122} (filter program), and DP_{123} (formatting program). The related DM is:

$$\begin{bmatrix} FR_{121} \\ FR_{122} \\ FR_{123} \end{bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{bmatrix} DP_{121} \\ DP_{122} \\ DP_{123} \end{bmatrix}. \quad (4)$$

FR_{13} receives and transfers the data or information on positions of vehicles or control between DP_{12} and DP_{14} with networks such as Ethernet, WiFi, GPRS, the data running on which should be consistent with their protocols. The decomposition of FR_{13} and its solution is formulated by:

$$\begin{bmatrix} FR_{131} \\ FR_{132} \end{bmatrix} = \begin{bmatrix} X & 0 \\ X & X \end{bmatrix} \begin{bmatrix} DP_{131} \\ DP_{132} \end{bmatrix}, \quad (5)$$

Where FR_{131} is receiving and sending out data, FR_{132} is transferring data, DP_{131} is network terminals and DP_{132} networks. The network terminals depends on the type of network chosen, including ones for Ethernet and wireless networks. Generally, wireless terminals close to information gathering module are supposed to give more priorities to decrease the cost and difficulties.

For FR_{14}, it receives, splits the data from networks, and judge the position of current vehicle at current time based on database, where the coordinates of RFID readers are stored, then displays it on GIS, as well records the position information of vehicles. Additional, other extended applications are based on FR_{14} like intelligent charging. It can be implemented as follows.

$$\begin{bmatrix} FR_{141} \\ FR_{142} \\ FR_{143} \\ FR_{144} \\ FR_{145} \\ FR_{146} \end{bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 & 0 \\ X & X & 0 & 0 & 0 & 0 \\ 0 & X & X & 0 & 0 & 0 \\ 0 & X & 0 & X & 0 & 0 \\ X & 0 & 0 & 0 & X & 0 \\ X & 0 & X & X & 0 & X \end{bmatrix} \begin{bmatrix} DP_{141} \\ DP_{142} \\ DP_{143} \\ DP_{144} \\ DP_{145} \\ DP_{146} \end{bmatrix} \quad (6)$$

Here FR_{141} is preprocessing and outputting data which, FR_{142} splitting and judging position, FR_{143} displaying position on the map, FR_{144} recording the position data in database, FR_{145} controlling vehicles, FR_{146} extended applications, DP_{141} interface program, DP_{142} position inquiry program,DP_{143} map and displayer, DP_{144} database and saving connector, DP_{145} control implementation program and DP_{146} is further application collection including cargo tracking , anti-theft tracking and so on, whose details are referred in Figure 3.

3.2 Basic Steps of Vehicle Tracking based on RFID

Compared with past vehicle tracking systems, the new one based RFID presented in the design above mainly uses RFID technology as the core part. There are RFID tags, RFID readers, network terminals, databases, application servers for the data center, GIS or maps, and so on.

In order to locate the vehicle positions by RFID, it is assumed that the RFID readers have been deployed on roads or at key spots, whose deployment information is combined with maps, RFID tags have been equipped onto the tracked vehicles, all the information about the RFID readers and the vehicles have been stored into the database.Sequently the vehicle positions can be obtained by checking the combined information of RFID tags, readers and maps.

As a matter of fact, the information about the tracked vehicle can described by a triple *TD* (*T*,*R*,*t*), here *T* is the vehicle tag information including tag serial number, vehicle number and others, *R* represents the unique number of the RFID reader identifying the current tracked vehicle, which is stored in the control part of the reader, and *t* is the time to get the vehicle information. These three parts of the *TD* are integrated into one group by the control part of the RFID reader according to the processing and encoding rules, then are transmitted to the closest data center, where the combined data *TD* will be checked to attain the position of the tracked vehicle. The following steps are involved to track a vehicle, as shown in Figure 2.

(i) identify the vehicle tag information *T* by a RFID reader on the roads.
(ii) combine *T* with *R* and *t* ,then get a *TD*.
(iii) send the *TD* to the closest data center by networks.

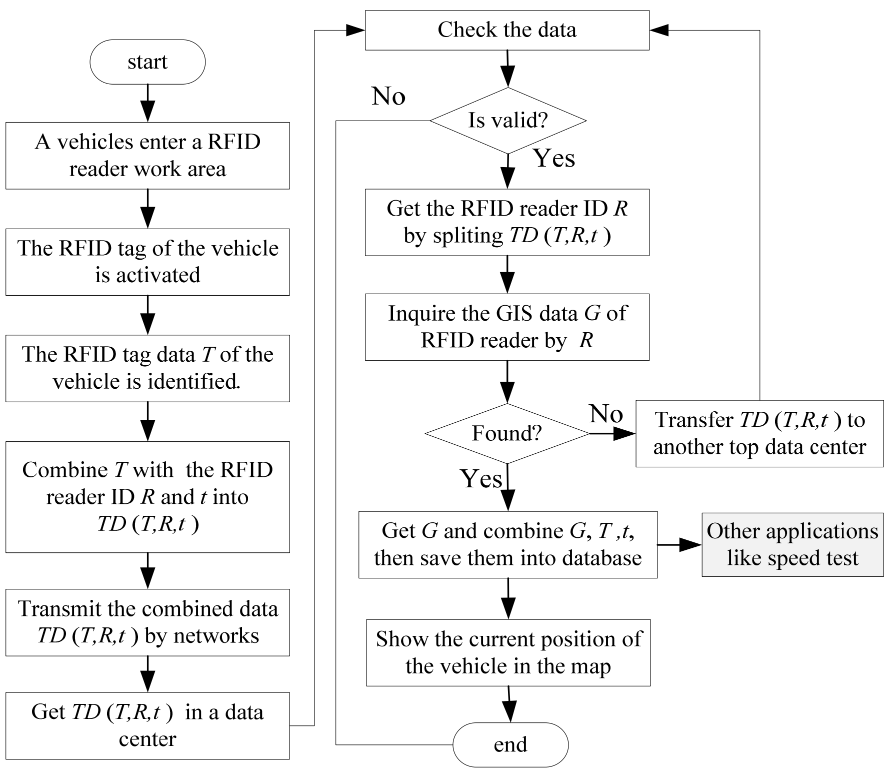

Figure 2. Steps for Each Vehicle Tracking based on RFID

(iv) get the *TD* and check if the *TD* is valid. The data check steps depend on the pattern of data transmitting.Two patterns of RFID data transmitting are proposed as described in section 2 in this method. For pattern 1, since all transmitted data have been filtered, here only to check the the gotten data is integral or modified. For pattern 2, in addition to checking the integrity of the gotten data, it is necessary to search the vehicle data in the gotten data, because there is possibility of taking other types of RFID data like cargo information.

(v) get the RFID reader's number *R* through splitting the *TD*.

(vi) get the RFID reader *R*'s position *G* through inquiring GIS or RFID reader database by *R*. The *G* is also the vehicle's position on *t*.

(vii) show the position on the map or do further handling.

4. Architecture of the Vehicle Tracking System

According to the design above, there are RFID tags, fixed RFID Readers, network terminals, databases, application servers and maps in the new VT system based on RFID. All these physical parts can be extended according to actual applications, also can collaborate with other tracking techniques like GPS, for instance, portable RFID readers can be imported to remotely check goods in transportation. The databases and the application servers compose the data handling center of the new vehicle tracking system. This system can classified logically into six layers, as shown in Figure 3, namely, from bottom to top, Database Layer, Physical Layer, Network Layer, Enabled tools Layer, Application Layer and User Layer. The database layer, enabled tools layer, application layer and user layer are all implemented by the data handling center.

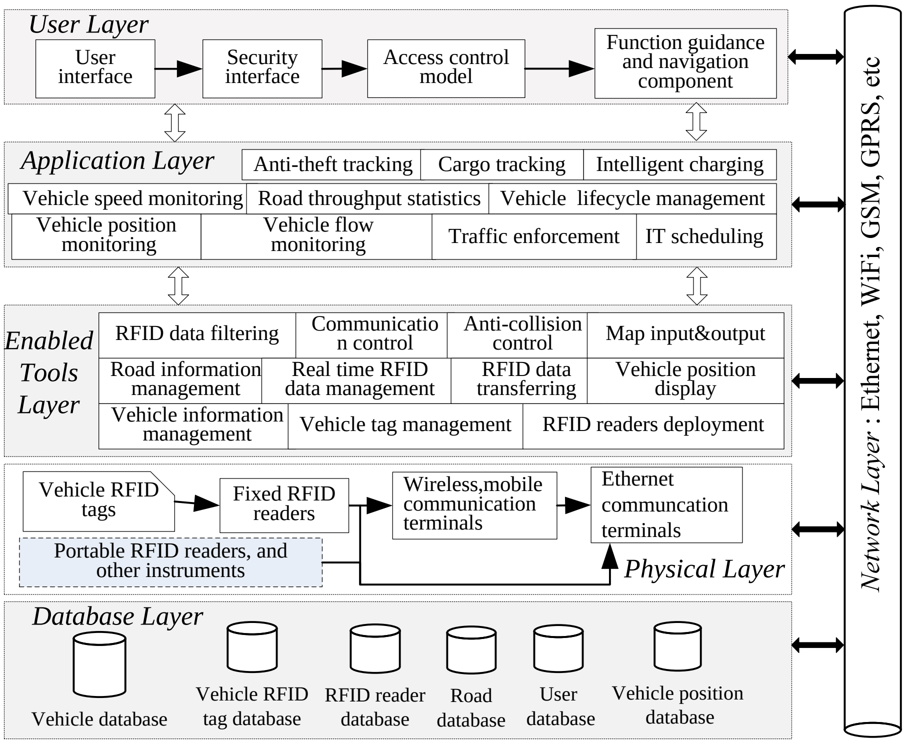

Figure 3. Architecture of the Vehicle Tracking System Based on RFID

The database layer, or layer 1, is the storage of this new vehicle tracking system, and consists of several kinds of databases involved in this system. It provides judgment standard and stores realtime data for the process of tracking vehicles.It is defined as the base of tracking vehicles or other advanced applications. In order to track vehicles by RFID, this layer mainly includes the vehicle database, the database of vehicle RFID tags, the database of RFID readers, the information of RFID tags tracked, the position information of vehicles, road information, and user information.And the vehicle database records the information of tracking and tracked vehicles, referring as the number, the type, the manger and other information related to a vehicle, which can directly come from the basic data of a vehicle presented by its manufacturer.

Layer 2, Physical Layer, is a fundamental layer of collecting information and the input of the tracking system. It mainly gathers RFID tag information of moving vehicles, preprocesses these information and encodes, then transforms them into information which is suit to take the networks, at last sends out them through the networks. Due to using RFID readers and tags to get vehicles' position information, the physical layer is the major difference from the traditional tracking systems. This layer provides a benchmark for RFID tag selection, reader selection, the functions of readers, the steps and algorithms of information preprocessing and encoding rules. Thus, it comprises main hardwares related to RFID, just like RFID tags, RFID readers, network terminals and corresponding standards. All these hardware can be added and extended according to the application requirements. Generally, passive RFID tags, placed on the tracked vehicles, are used to identify vehicles, which save the basic information about each vehicle including its unique number, the types, the owner, the buying time, and so forth. These basic information should match with the vehicle tag database in Layer 1. Fixed RFID readers are suggested to used to identify the vehicle tags or cargo tags, which are deployed at the sides of roads and in other important areas, and their position information is saved in Lay 1 as well. Preprocessing data is required in these fixed readers, which combines the RFID data with readers' self identification information. According to the overall functions of this layer, the network communication interfaces on RFID readers are also demanded so as to connect with network terminals, which send out the combined data about vehicle positions through Lay 3.

Since the RFID readers on the roads can read other non-vehicle tags, as well in order to decrease network load, it is essential to optimize the information in RFID tags, at the same time filter before transmitting.Hence It needs RFID readers with data processing function. Two patterns are concerned the data transmitting of RFID readers.

(i) Transmitted after filtered. In this pattern, a data processing chip is integrated into each RFID reader, goods type information should be saved in each RFID tag, and the type code for vehicles is prepared and set in the chip. Therefore the data processing chip can check and filter each tag information by comparing the type code in tags with its code. If the match is successful, the tag data is going to be sent out. By this way, the network load is reduced.

(ii) Transmitted before filtered. Compared with Pattern 1, the data collected by RFID readers are directly transmitted without type consideration, whose filtering is then finished by the data center according to the type code. Consequently the network load is higher than Patter 1, which will require wider network and make the networks busier. Furthermore the data center should process more data, and more data security problems will be faced due to lacking of discriminating data. But it is helpful to decrease the cost of RFID readers, at the same time, since the data of all types of tags are delivered to the data center, more deep and further applications can be easily developed.

The third layer named Network Layer, namely DP13,provides the basic transmission networks for the system, containing the physical network terminals, the communication networks among the RFID readers, the data center and other distribution data handling parts, guaranteeing transferring the combined vehicle tags information in the physical layer to the data center and getting the analysis results back efficiently and without errors. Ethernet, WiFi, GPRS or 3G network can be applied to this system.

Lay 4 is the enabled tools layer, made up of the basic software tools for tracking. The major functions or modules are listed as the vehicle RFID tag management, the goods tag management, the RFID reader management, the order management, the position judgment of RFID tags, and so on.

Based on the basic tools in Lay 4, further, compound or specific applications directly oriented users are involved in the application layer. According to the future trend, a lot of higher and intelligent application functions can be achieved only by simply developing and integrating, such as vehicle position tracking, automatic vehicle charging, goods tracking, automatic speed detection, road throughput statistics, vehicle flow-rate calculation, etc. These applications can be used by traffic management departments, police and logistics companies to schedule transport, track criminal vehicles , track theft and automatically count goods, which improves the service level of government and companies, as well as the convenience and intelligence of our society.

The user layer points all kinds of users using this system and the relevant control functions provided by software toolkits.The user group main involves distribution centers, logistics companies, vehicle owners, traffic management departements, customers and other government departments. For guidance and security, some basic control functions are introduced into this layer like user management (user account registration, cancellation,et al), access authorization and access guiding. Thus the personal interface of the system, the user security authentication interface, the security control model and the component for automatic function access guiding are included in this layer.

5. An Application Case

Under the guidance of the architecture above, a cargo tracking system was developed, where UHF-RFID tags and relative readers, Sogou map and SQLServer 2008 were involved.In addition to fixed readers deployed on the roads and tags of vehicles, tags for goods and portal readers were also used.This system implemented functions including basic information management, order management, tag management, RFID reader management, vehicle management, cargo information query, and so on. It supports designing layout of RFID readers on the map then saved in SQLServer 2008, recording and displaying positions of a vehicle, as well as checking cargo information like realtime distribution status. Figure 4 and Figure 5 are the Sample of RFID reader deployment and cargo positions respectively.

Figure 4. RFID reader deployment sample

Figure 5. Cargo tracking results

6. Conclusion

This paper develops the basic steps of tracking vehicles by RFID, and puts forward an architecture of the vehicle tracking system based on RFID, where there are six layers including the database layer, physical layer, network layer, enabled tools layer, application layer and the user layer. Compared with past traditional vehicle tracking methods, the kernel of the tracking method constructed on the architecture above is RFID technology. The architecture with high openness to future technology, organizes different functional parts of a tracking system with clear levels, which makes it can be easily extended and put into effect. In the future, we will develop practical applications according to the architecture.

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