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IMPLEMENTING VEHICLE LOCATION SYSTEM FOR PUBLIC BUSES IN SINGAPORE

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ABSTRACT

A Vehicle Location System will be implemented in Singapore in conjunction with the contactless smart card-based bus ticketing system to provide automatic fare deduction. The Vehicle Location System is GPS-based but uses the odometer and gyroscope to provide dead reckoning. This paper discusses the system architecture of the Vehicle Location System and the technical challenges in implementing the system.

INTRODUCTION

On April 13, 2002, Singapore launched its contactless smart card (CSC) system for public transport (Wang, 2002; Sim et al., 2003). A part of this system is a Vehicle Location System that tracks the location and movement of public buses and hence determines fare automatically that needs to be paid by a passenger.

BACKGROUND

The new payment system allows payment of fares for bus and train travel through the use of a CSC. In Singapore, bus fare is distance based i.e. fare is determined by the distance travelled. The new payment system introduced a feature whereby bus fares are automatically calculated and deducted from the passengers' CSC (Prakasam and Wang 2002). Automatic fare calculation on buses is possible with the introduction of the "check-in and check-out" process on buses. Basically, passengers are required to present their CSC based ticket at a Bus Entry Processor (BEP) when they board the bus and present their ticket again at a Bus Exit Processor (BXP) when they alight. This will create a closed loop system somewhat similar to the fare payment arrangement adopted by most rail transit systems in the world where the passengers go though a set of entry and exit gate at their origin and destination stations respectively. The BEP writes to the ticket information needed for fare calculations. The BXP calculates and deducts the appropriate fare from the ticket. The enabling technology is the Vehicle Location System (VLS) on board the bus which provides information of location of the bus to the BEP and BXP. It is part of the bus ticketing system that helps to provide the fare stage information to calculate the fare for the alighting passenger.

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SYSTEM OVERVIEW OF THE BUS TICKETING SYSTEM

Figure 1 provides the system overview of the CSC based on-board Bus Ticketing System. The system consists of the following:

1. <u>Two Bus Entry Processors (BEP)</u>

The BEPs encode sufficient information of entry on the ticket so that the appropriate fare due can be calculated when passengers alight from the bus. They also display the remaining value on the ticket to passengers. They are placed near the entry doors for processing CSC based tickets when passengers board the bus.

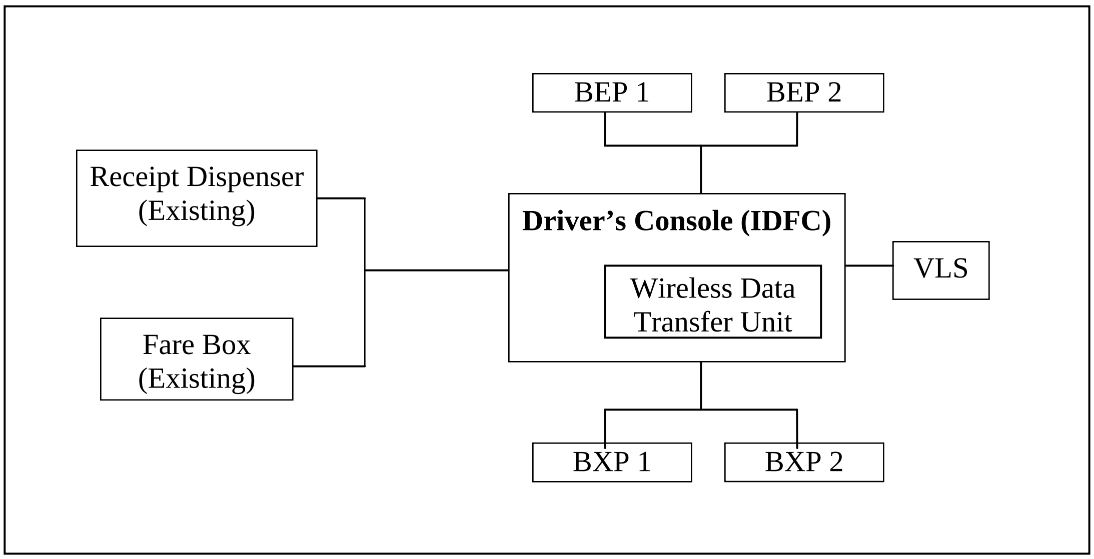

Figure 1: CSC Based On-Board Bus Ticketing System

2. <u>Two Bus Exit Processors (BXP)</u>

The BXPs read the boarding information on the tickets, calculate and deduct the appropriate fare. These processors also display remaining value on the ticket to passengers. They are placed near the exit doors for processing CSC based tickets when passengers alight from the bus.

3. <u>Vehicle Location System (VLS)</u>

The VLS determines the location of the bus through its interface with the GPS receiver, bus odometer and door opening/closing signal. It then provides information of the fare stage to the driver's console to determine the fare stage for fare calculation.

4. <u>Fare box</u>

The fare box is used to collect cash fares. It was part of an existing system used for magnetic tickets and integrated into the CSC system.

5. <u>Receipt Dispenser</u>

The receipt dispenser is used to dispense receipt for payment of cash fares. It was also part of the magnetic ticketing system and was integrated into the CSC system.

6. <u>Driver's console</u>

The driver's console is termed the Integrated Driver Fare Console (IDFC). This console is the brain of the on-board bus ticketing system. It stores information such as the fare stage and fare tables. It also provides this information to the BEP and BXP and updates them each time there is a fare stage or table change. The console provides the driver an interface to the ticketing system for driver's login/logout, issuing cash fare receipt, cancelling of boarding for passenger who boarded the wrong bus and updating of fare stage when the VLS is out of service. The console also has a wireless data transfer unit for automatic transfer of data from the bus to the depot computer when the bus returns to depot.

SYSTEM OVERVIEW OF THE VEHICLE LOCATION SYSTEM

The main function of the VLS is to determine the location of the bus and provide fare stage information to the IDFC. The VLS uses a combination of GPS, gyroscope, odometer and door switches to determine position and compares this with route data to report the bus position.

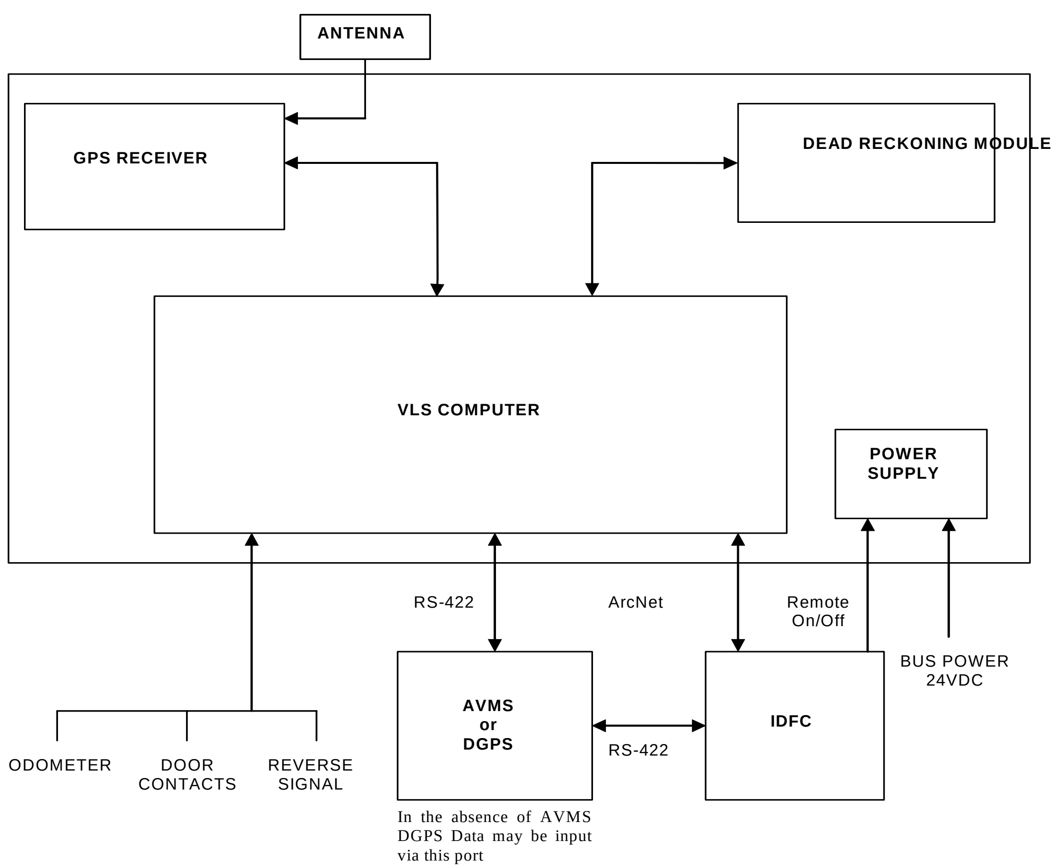

Figure 2: System Diagram of the VLS

Other than providing location information, the VLS will also interface with the bus operator's Automatic Vehicle Management System (AVMS) to provide real-time location information. Figure 2 shows the system diagram of the VLS. The VLS consists of the following components:

1. Main computer

The main computer incorporates the microprocessor, memory and all electronics that are required to perform position calculation. It has a volatile memories that has a minimum of 100 hours of memory retention when the power supply is removed.

2. Communication ports

There are four types of ports on the VLS. There is the IDFC Local Area Network (LAN) port that operates using Transmission Commission Protocol (TCP) running over Attached Resource Computer network (ARCnet), the RS-422 AVMS port, the bus signal port that interfaces to the odometer, door switches and reverse signal on the bus and the power port that taps power from the 24VDC bus power supply.

3. Dead reckoning module

The dead reckoning module includes a gyroscope for bearing information. This module derives position from the gyroscope and bus signals when no GPS signal is available.

4. GPS module

The GPS module gathers information via satellite to calculate position and also provide accurate current time. The module has 8 channels, DGPS capability and position precision of less than ± 100m (2drms). Its hot time to first fix (TTF) is less than 60 seconds and cold TTFF is less than 15 minutes.

5. Antenna

The antenna for the GPS module connects via a connector to the VLS enclosure. The antenna (if roof mounted) does not exceed a height of 5 cm and is designed to be sufficiently robust to prevent damage by low vegetation or bus wash brushes.

6. Power supply

The power supply incorporates appropriate circuitry to handle voltage variations and transients. It accepts a remote on/off signal from the IDFC.

LOCATION DETERMINATION AND FARE CALCULATION

In order to determine the fare that a passenger should pay, the bus system have to first know its position with respect to the bus route every time a passenger entry or exit process their CSC at the BEP and BXP respectively. The VLS provides this information by making use of a series of other information such as GPS co-ordinates and information bus route, bus stop location and input from odometer and dead reckoning module.

In CSC based system, for every bus service route that is operated by a bus operator, a bus service table is defined in the system. Table 1 shows a simplified bus service table used in the system. In every bus service table there is a series of markers. They represent the locations the bus will pass through if it is running the particular service route. On a separate table, each of these markers has a GPS co-ordinate assigned to it. The table can define up to 30,000 markers although currently only about 7000 markers are used for the all the bus services in the whole of Singapore. There are close to 300 bus services in Singapore.

Table 1: A Simplified Bus Service Table

Service Number: 170 Scheme: Aircon Trunk					
Direction: Outbound					
Marker ID	Active Markers *	Distance to next marker (in metres)	Stage no. (of Stop)	Half-Stage	Stop ID
1044	S	290	1		1234A
10115	W	380			
10176	W	442			
1476	S	280	1	√	1235A
…	…	…			
2431	S	505	22		6137C
…	…	…			
Direction: Inbound					
Marker ID	Active Markers	Distance to next marker (in metres)	Stage no. (of Stop)	Half-Stage	Stop ID
3250	S	299	1		6790Z
4346	S	404	1	√	6789Z
…	…	…	…		…
2431	S	389	16		6137C
…	…	…	…		…
3275	S	551	25		1247Z
10446	W	393			
…	…	…	…		…

* S – (Bus) Stops, W – Way-points

The bus service table indicates whether a marker is a bus stop or a way-point. A way-point is a location along a bus service route that is not a bus stop. Based on the marker information, the VLS determines where the bus is along a service route by comparing the GPS co-ordinates received by its GPS module and the information provided in the bus service table. If the reading is within the radius of certainty to a marker, then the VLS can confirm that the bus is at that marker. The radius of certainty is a system parameter that is set to 20 metres. If there is no match all the time as the bus may be somewhere between two markers, the VLS have to wait a while before trying again.

If a marker on the bus service table is a bus stop, other information such as bus stop ID and stage number are also included in the bus service table. Every bus stop along a bus

service route has been assigned a stage number. The assignment of stage number is based on distance between two consecutive bus stops.
For fare calculation, the bus ticketing system makes use of the stage numbers assigned to the boarding and alighting bus stop. The stage difference or stages travelled will determine the fare to be charged. For example, Table 2 shows the fares charged by bus operators on an Adult CSC for travelling on trunk services, as at April 1, 2003. A passenger with an adult card and having travelled 6 fare stages on a non-air conditioned trunk service would have 68¢ deducted from his card when he alights from the bus.

Table 2: Fare charged by bus operators as at April 1, 2003

Fare Stages	**Adult Trunk Fare**	
	Non Air-Con	**Air-Con**
4 and less	58¢	63¢
4.5 – 7	68¢	83¢
7.5 – 10	78¢	$1.03
10.5 – 13	88¢	$1.13
13.5 – 18	98¢	$1.23
18.5 – 23	$1.08	$1.33
23.5 – 29	$1.18	$1.43
29.5 and more	$1.28	$1.53

IMPLEMENTATION CHALLENGES

Implementing an accurate Vehicle Location System has its challenges. The basic inputs to the VLS are GPS signals from satellites. In a dense environment with numerous high rise buildings, a commonly known problem occurs, termed the Urban Canyon effect. The bus travelling on the road right at the bottom of the concrete canyon is prevented from receiving GPS signals as tall buildings block out signals from the satellites. In such situations, the VLS goes into dead-reckoning mode. In this mode, the VLS make use of the odometer and gyroscope to determine its location with reference to the last known GPS co-ordinate. The accuracy of such method is not consistent.

Although the odometer has a good sensitivity (±2%), it becomes inaccurate due to tyre wear and tear. Hence after the odometer is calibrated, the accuracy decreases with wear and tear of the tyres to about ±5%.

The gyroscope is useful for tracking movements parallel to the road. It provides the acceleration vector in the horizontal plane; that is, longitudinal and transverse acceleration to the road can be measured. Consequently, the distance along the road can be established by integration and the perpendicular to the road is differentiated out from the odometer input that would then serve as a check and also provide correction factors.
Another challenge faced by the VLS is road repair works or temporary road diversions which affect distances between markers. A bus has to make diversions to its original route and change the distance travelled, it affects the accuracy of the VLS when in dead-reckoning mode. For longer terms road repair works and road diversions, the problem is

overcome by providing new sets of markers to the bus for the duration of the work. For short term disruption to the route where the disruption is over by the time the route survey is done and ready for distributing to the buses, the problem have to be left as it is.

When receiving GPS signals, the GPS co-ordinates calculated (with dead reckoning) has an accuracy of up to ±20 metres for 90% of the time. In Singapore, where there are bus stops on two-way roads, there is often another bus stop on the opposite side of the road. Bus services that serve these bus stops will also come back on this road in the opposite direction on its return trip. The bus stops opposite each other are often less than 40 metres apart, within the buffer range of the GPS co-ordinates. The VLS software has to figure out whether the bus is still on track, gone off route or has it cut short its trip. This situation is worsened for loop services whereby part of the route is for the bus to make a turn and go back on the same road back to the terminal. For this reason, the VLS software was modified such that when VLS detects an off route situation, it will hunt for a match on bus service table from the most current confirmed marker onwards instead of the entire bus service table to improve the accuracy of the VLS.

The bus doors generally open when it reaches a bus stop. Hence when the bus is at the bus stop, its GPS reading should match the pre-entered GPS co-ordinate of the bus stop marker. In the VLS, it is programmed such that when the bus doors open, the GPS receiver will capture the local GPS co-ordinate and the VLS will compare it with the pre-entered GPS co-ordinate to confirm its location. If the actual GPS co-ordinate is within the radius of certainty of the pre-entered GPS co-ordinate, the VLS will update the fare stage information accordingly. If the actual GPS co-ordinate and the pre-entered GPS co-ordinate differ beyond the radius of certainty, the VLS will search through the list of GPS co-ordinates of that service route. One of the following two scenarios may happen.

a) If it finds a corresponding GPS co-ordinate, it will compare with dead reckoning for discrepancy as explained above

b) If it cannot find any corresponding GPS co-ordinate in the bus service table, the fare stage that was determined by dead reckoning will be retained.

In the case of the second scenario, if there is extremely poor GPS reception, the VLS may remain permanently in the dead reckoning mode and throw the VLS totally off course and result in wrong fare charges. To avert this problem, if there is 5% discrepancy between GPS and dead reckoning, the VLS is programmed to send an error message sent to the driver’s console to inform the driver to take over the stage updating. This way, failure of the VLS will also not affect the overall operation of the bus ticketing system

Lastly, in the VLS, the pre-entered GPS co-ordinates themselves have to be accurate. The method of collecting these GPS co-ordinates is to drive along the bus service route and take down GPS readings at bus stops and way-points. GPS readings from a hand-held device can be accurate up to 5m only if the device remains stationary for a while for it to take multiple readings and eliminate any errors through averaging. However, road conditions may prevent the person operating the device from remaining stationary for the time needed or stopping right at the bus stop or ideal way-points. This leads to some inaccurate pre-entered GPS co-ordinates in the system. The inaccuracy led to the VLS not being able to find a match even though the bus is at the correct location. For this reason, before a particular service route can be commissioned for revenue service using VLS, a thorough check is done. This check involves driving a bus along the route at least twice with the VLS turned on. If the VLS is able to accurately determine its location without much manual intervention by the driver, the route can be commissioned. Else, the GPS co-ordinates of the markers are re-surveyed to get and checked.

The key factor to an accurate VLS is the level of intelligence built into the system. The VLS needs to integrate accurate information from various sources such as the door signal, the odometer, the gyroscope and the GPS module into a sophisticated 'learning' algorithm. With constant updating, fine-tuning and testing, the VLS can consequently be extremely accurate in predicting bus location and providing accurate fare calculation.

CONCLUSION

The VLS is a location positioning system that enables the CSC based bus ticketing system to automatically deduct fares. It makes use of GPS co-ordinates, odometer signal, gyroscope signal and door signals to determine where along a bus service route a bus is. Availability and accuracy of these input signals affect the implementation of an accurate VLS system.

While the Vehicle Location System is considered a well-established technology, its application in buses requires specialised skills and significant effort in refining the algorithm to match the characteristics of the bus operations. With progressive fine-tuning the VLS will be a reliable system for location positioning and fare calculation.

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