Verification of INS/Vehicular Technology in Parking Garage Service using DSRC and Mobile Communication

C. W Hsu, C. N. Liang, H. Y. Huang, Y. C. Shiue and S. C. Huang

Abstract—**A traditional parking lot is managed by manpower, and perhaps there are also plenty of advanced areas which are auxiliary installed with RFID or IR equipment. However, this kind of state is constrained with limit service and bounded in fixed style. This paper presents an innovative concept of close service for parking guidance. Driver can make an appointment by cell phone in thirty minutes before, and furthermore the service platform will book a parking space for driver. The parking lot location will be marked in a map and transmitted to vehicle screen when vehicle pass through entrance using DSRC communication. After driver successfully drive to scheduled parking lot, parking server will send a message to driver cell phone in order to log the final vehicle location. The developed system, SmartValet, is also available in underground parking. The autonomous ability is integrated different sensors to offer robots or remotely operated systems a reliable navigation means. In system technology, it addresses a global and all weather navigation design based on GPS positioning, gear-box speed, odometry and inertial measurement unit in dead reckoning. Positioning uncertainty will grow with time as a result of integration error so the performance will lose accuracy. To solve this shortcoming with error bounded, this paper uses a creative idea which driver clicks and drags touch panel to give a new position and heading. The proposed system is carried out with theoretical application and hardware integration, and furthermore the result shows navigation ability and intelligent approach applicability.**

I. Introduction

HAVE you ever parked a car a few hours before, but you forget the location? Have you ever hurried to a conference, but you spend a lot of time finding a parking lot in parking tower or underground parking garage? You will look forward to getting a navigator to find an exact route. Basically, a navigator can improve efficiency in parking, energy saving and emission reduction with parking guidance system. Although it is easier to know own location mapped onto GIS by GPS positioning, a vehicle operation may be located on the road or inside the buildings. Under such conditions, GPS loses its superiority of positioning and navigation. The inertial navigation system (INS) can overcome this shortcoming by inertia sensors [1]. The acceleration and spatial information can be obtained from accelerometers and gyroscopes of any moving platform. INS error accumulates due to inertial sensor's performance with time that long period performance of INS becomes less accurate.

A vehicular unit (VU) could sense vehicle speed and heading by calculating odometry. Although lower accuracy inertial sensors might cause the integration error with time in speed and vehicle spatial motion, VU could provide continuous speed and heading with movement through controller area network (CAN). As a result, an idea of INS and VU integrated system tries to adopt commercial GPS and inertial sensors to construct a higher reliable and better accurate navigation in lower cost platform. In order to limit INS navigation errors, the INS position information could be updated in accordance with GPS, and vehicular data information is update and enforced by VU data acquisition and computation.

In the recent two decades, wireless communication had a tremendous growth in many applications. Cellular systems, infrared, Bluetooth and dedicated short range communication (DSRC) in wide area or local area communication have rapidly increased. A general vehicular communication which depends on its coverage area can be classified into four categories: inter-vehicle, outer-vehicle, vehicle-to-infrastructure and vehicle-to-vehicle. Between on-board device of vehicle and parking server, DSRC module which is a wireless communication protocol in the 5.9 GHz frequency band plays an important role of bridge [2]. The system architecture of DSRC is based on IEEE 802.11p standard to WAVE protocol. For real time messaging, a common communication can reversely be implemented to switch into user datagram protocol(UDP) to receive packets and forward self-information to other devices [3].

This paper presents an integrated system to construct a parking garage service platform using data fusion for vehicle, DSRC for driving navigation and 3G for parking lot management. Combining with the GPS/IMU integration, the vehicular signals may play a potential auxiliary support to derive another package of position and moving information to

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enhance the autonomous capability. The DSRC application and on-line surveillance had been presented in ARTC [4] [5]. In addition, the parking garage server workstation proposed in this study consists of parking lot host, parking guidance and information server as well as internet browser. The concept is a parking lot guidance system which is combined telematics technology with indoor navigation technology. This extended system not only indicates the route in indoor navigation aid but also offers reservation in parking lot and sends immediate message in air to hint you a free slot of added valued service. It will equal to animated valet parking attendant to do on-line service, moreover it will help you to park in indicated lot. The system is respectfully called as "SmartValet" .

II. Parking Garage Service Platform

A parking garage service platform is built of three mainly components, including INS unit, user unit and server unit in demonstrated scenario. The architecture of the proposed system is shown in Fig. 1 below. The INS provides autonomous independent means for 3D positioning with high short-term accuracy and degrades over a short period of time when GPS suffers poor availability, e.g., due to indoor, underground uses or blocked satellite signals. Integration of GPS with an IMU improves the quality and integrity of navigation ability. Integration of VU with GPS is usually applied to keep GPS position error to a minimum [6]. INS could assist system to correct the integration error of vehicle speed with time and plays secondary equipment.

When a driver uses cell phone to book a parking lot via website, the parking management system can demonstrate the importance if it can meet the requirements of a driver by showing the space location in vehicle panel. These operation procedures are shown in Fig. 2. After vehicle driver into parking area, the parking garage server will broadcast parking MAP to vehicle using DSRC [7]-[11].

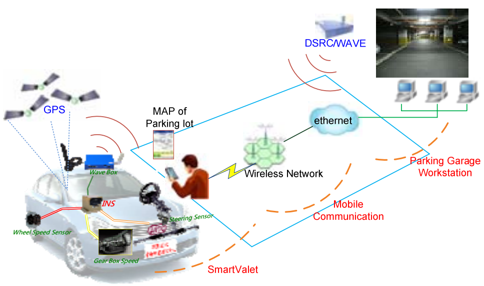

Fig. 1. The architecture of parking garage service system.

Fig. 2. The flow chart of operation procedures.

A. *Inertial Navigation Unit*

An autonomous platform is built of the basic four parts of processing core; IMU sensors with accelerometer and gyroscope; GPS Receiver and vehicular information. The block diagram is shown in Fig. 3. The dsPIC30F6014 is chosen as core controller to handle real time message. Time slots are used to process and measure the inertial and GPS data through universal asynchronous receiver and transmitter port. The core is designed to perform as supervisor core, where GPS message and inertial analog signals are on-lined captured/sampled and processed, back to the DSRC application; while the vehicular data is determined as the calibrated information. This INS core has the communication interface to a personal computer IXP to downlink messages and broadcast.

An IMU is a closed system that is used to detect altitude, location, and motion. It normally uses a combination of accelerometers and gyroscopes to track the vehicle motion in attitude and location. The IMU is capable to transmit inertia data from core to IXP, where the interface is full duplex UART2. In order to output vehicle spatial states, it is accomplished by integrating an output set of sensors, such as gyros and accelerometers. Gyros measure angular rate with reference to inertial space, and accelerometers measure linear acceleration with respect to vehicle's frame.

In this development, a commercial GPS module as Skytraq FGPMMOPA5 is chosen for its high performance, low power consumption, small size, based on the well-verified technology. In system operation, the system needs to have speed calibration function in order to correct speed integration error. This processing technique utilizes wheel speed sensor to provide raw signal, and it is measured by hall sensor. Using charge-pump chip (LM2907) to convert signal's frequency to voltage varying from 0 to 5 volt, the sensing technology used AD interrupts to calculate average voltage. In low-speed, wheel speed from odometry whose response is very slow is not available to get on-line information. Gear-box speed is used as assistant secondary device.

B. *Booking design between user unit and server unit*

The mission of parking lot host is to report the total number of parking space and the number of real-time availability to parking guidance and information server as basic module. The mode to report employs client-server architecture, where parking lot host is server, parking guidance and information

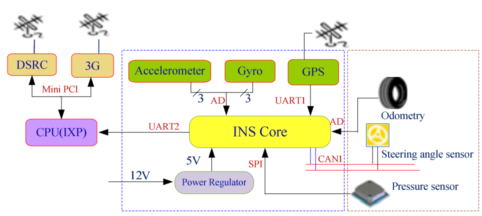

Fig. 3. Block diagram of autonomous platform.

server is client. Parking guidance and information server downloads the real-time information on parking space available via internet per the fixing interval.

The principle to establish parking lot information and guidance system protocol is that the system worked out in an early phase is integrated in accordance with packet, cost and stability to establish communication protocol. The protocol format follows as <ID>,<CMD>,<Address>,…,<CRC> which is referred to Taipei City Parking Lot Information and Guidance System [12]. After the real-time information is transmitted from each parking lot, a server will save the real-time parking space information in SQL Server 2000 database for users who can inquire the real-time information from parking lot near the destination. The connection between parking guidance, information server and parking lots host is based on the client-server architecture. The client is parking guidance and information server, which downloads the number of parking space available in real time via internet. After receiving the real-time information on parking space available from each parking lot, the number of parking space in database is updated for user inquiry.

The booking procedure is finished by entering car identification and cell phone number, such as 8133-XX and 0928920XXX. If this booking operation is finished, the website will send a message to user phone via mobile network, as shown in Fig. 4.

C. Entrance/Exit strategy between user unit and server unit

The connection between internet browser and parking garage server is based on the client-server architecture. The client is internet browser at user end which provides the information on current parking lot destination via internet. A server is parking garage server which receives the information from internet browser. Furthermore, it also returns the information of parking space available and a guidance map of parking lot near the destination using DSRC when vehicle entrances, as shown in Fig. 5(a). The OBU will receive parking area map and guide to scheduled parking lot.

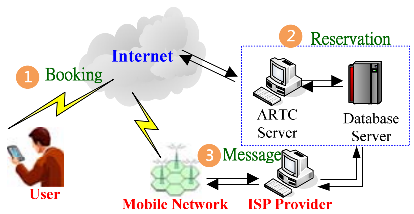

Fig. 4. IMU circuit board which is installed in trunk.

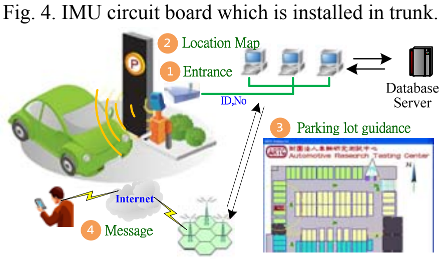

Fig. 5(a). Entrance and operated procedures.

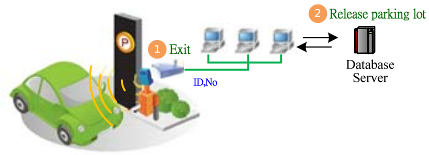

Fig. 5(b). Exit parking area and its operated procedures.

In reverse scenario, vehicle drive to exit and DSRC will use two-way communication and do data exchange in order to calculate vehicle trajectory. The trajectory can be used to decide entrance or exit. In Fig. 5(b), the mission of parking server is to report the total number of parking space and the number of real-time availability to database.

III. PRINCIPLE OF SYSTEM ALGORITHM

The parking garage system has two key technologies, including inertial integrated navigation, on-line GIS correction. In the integration of GPS with IMU, GPS provides a precise global positioning and IMU offers independent spatial sensing as complementary performance. If the vehicle has low dilution of positioning DOP, VU is the redundancy instead of GPS positioning. The disadvantages of INS/VU integration are that mean-squared navigation errors increase with time and it is needed to be corrected or initialization. The on-line GIS technology is applied in remote position update.

In the inertial navigation data, the output states include latitude, longitude and altitude that require coordinate transform by adopting proper algorithms. These measurement data from IMU are three orthogonal components of body rotation rates and three accelerations in body frame [13]-[14]. Fig. 6 describes how to achieve inertial navigation via measurement and frame transform. The navigation algorithm contains several steps to compute vehicle attitude, earth rate, transport rate and Coriolis. The procedure to integrate acceleration, angular rates and calculate vehicle states in hardware is operated with software which is built in the microprocessor following the theoretical formulation below.

A. Attitude calculation - Quaternion method

Euler angles are the values which present the attitude of the vehicle. The attitudes of the vehicle mean the angles between body axes with navigation axes. There are three Euler angles

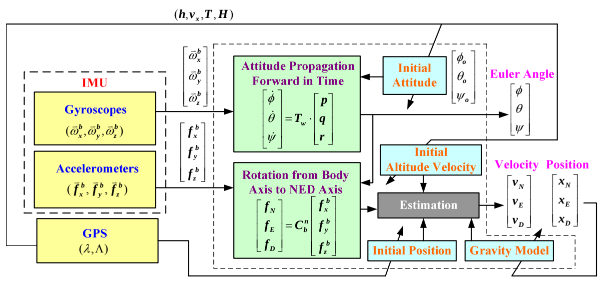

Fig. 6. The block diagram of algorithm in navigation. procedures.

φ, θ and ψ used to show the relative angles along x, y and z axis. The definition of Euler angles is shown in left part of Fig. 7. The Direct Cosine Metrics (DCM) is used to transfer information from one coordinate system into another coordinate system. It is carried out as a sequence of three successive rotations about different axes. The DCM mentioned earlier is limited since the solution become indeterminate when $q = 90^{\circ}$. The quaternion method is used to overcome this problem. The concept of the quaternion is based on the idea that a transformation from one coordinate frame to another can be effected by a single rotation angle δ and an orientation unit λ defined with respect to the reference frame in right part of Fig. 7.

In the quaternion transformation, the orientation is written as a vector which contains four elements with the magnitude of the rotation. The preceding about body-to-navigation DCM can be expressed through quaternion elements as (1). The q_i (i=0, 1-3) are calculated from kinematic equation in (2), and it can be substituted with the quaternion elements which is shown in (3). Refer to (3), vehicle attitude can be integrated and updated to get Euler angles.

$$C_b^n = \begin{bmatrix} q_0^2+q_1^2+q_2^2+q_3^2 & 2(q_1q_2-q_0q_3) & 2(q_1q_3-q_0q_2) \\ 2(q_1q_2+q_0q_3) & q_0^2-q_1^2+q_2^2-q_3^2 & 2(q_2q_3-q_0q_1) \\ 2(q_1q_3-q_0q_2) & 2(q_2q_3-q_0q_1) & q_0^2-q_1^2-q_2^2+q_3^2 \end{bmatrix} \quad (1)$$

$$q = \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} = \begin{bmatrix} \frac{1}{2}\sqrt{1+C_{b_{11}}^n+C_{b_{22}}^n+C_{b_{33}}^n} \\ \frac{1}{4q_0}(C_{b_{32}}^n-C_{b_{23}}^n) \\ \frac{1}{4q_0}(C_{b_{13}}^n-C_{b_{31}}^n) \\ \frac{1}{4q_0}(C_{b_{21}}^n-C_{b_{12}}^n) \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \\ \dot{q}_0 \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 0 & r & -q & p \\ -r & 0 & p & q \\ q & -p & 0 & r \\ -p & -q & -r & 0 \end{bmatrix}\begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_0 \end{bmatrix} \quad (3)$$

B. Velocity and position integral equations

The variations of velocities are integrated from the accelerations in the local geodetic frame. However, the measurements derived from sensors are in body frame. Therefore, the DCM mentioned earlier is used to transform the measurements from body frame into the local geodetic frame. The transformation is shown in (4).

$$\dot{v}^n = f^n - (w_{e/n}^n + 2w_{i/e}^n) \times v^n + g^n \quad (4)$$

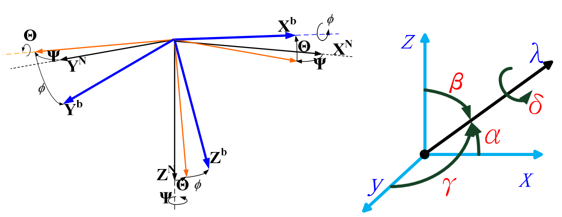

Fig. 7: Definition of Euler angles and Quaternion coordinate.

Owing to the Earth's rotation ($2w_{i/e}^n \times v^n$) and gravitation (g^n), the effect of the Coriolis force ($w_{e/n}^n \times v^n$) and gravity need to be corrected in (4). The position of vehicle is always described with longitude, latitude, and altitude (Λ, λ, h) in local geodetic frame. The navigation systems using on earth surface are mechanized or implemented such that the local geodetic frame is maintained while the vehicle is moving. The ellipsoidal model of the Earth is used to orientate the navigation frame with the variation position of the vehicle. The equations of the ellipsoidal are R_{meridian} and R_{normal}. Motion over the surface of the Earth is along the arc of the ellipsoidal surface. The changing rate of latitude and longitude are expressed in terms of R_{meridian} and R_{normal} in (5). The variation of altitude is equal to negative down velocity.

$$\begin{bmatrix} \dot{\Lambda} \\ \dot{\lambda} \\ \dot{h} \end{bmatrix} = \begin{bmatrix} \frac{1}{R_{meridian}+h} & 0 & 0 \\ 0 & \frac{1}{(R_{normal}+h)C\Lambda} & 0 \\ 0 & 0 & -1 \end{bmatrix}\begin{bmatrix} v_{north} \\ v_{east} \\ v_{down} \end{bmatrix} \quad (5)$$

C. GIS Correction – update position and heading

The prior discusses about mean-squared navigation errors increasing with time and it is corrected by HMI and GIS interaction. The on-line GIS technology is applied in remote position and heading update. From GPS coordinate, the procedure is transformed from WGS-84 to earth center earth fixed (ECEF) and ECEF to north east down (NED) frame using (6) and (7). The (7) uses relative position w.r.t selected origin point, as shown in Fig 8. The CAD coordinate is mapped into screen frame from 2nd order GPS projection.

The on-line correction is calibrated from finger click, and the screen position will be converted to NED position w.r.t CAD origin point. The vehicle position is calculated from last click position, and vehicular heading is delicate captured by first and last point. The moving direction is well calculated by recursive calculation when clicking screen trigger.

$$\begin{bmatrix} x^E \\ y^E \\ z^E \end{bmatrix} = \begin{bmatrix} (N+h)\cos\Lambda\cos\lambda \\ (N+h)\cos\Lambda\sin\lambda \\ [N(1-e^2)+h]\sin\Lambda \end{bmatrix} \quad N = \frac{a}{\sqrt{1-e^2\sin^2\Lambda}} \quad (6)$$

$$\begin{bmatrix} x^N \\ y^E \\ z^D \end{bmatrix} = \begin{bmatrix} -C(\lambda_0)\cdot S(\Lambda_0) & -S(\lambda_0)\cdot S(\Lambda_0) & C(\Lambda_0) \\ -\sin(\lambda_0) & \sin(\lambda_0) & 0 \\ -C(\lambda_0)C(\Lambda_0) & -S(\lambda_0)C(\Lambda_0) & -S(\Lambda_0) \end{bmatrix} \times \begin{bmatrix} x_1^E - x_0^E \\ y_1^E - y_0^E \\ z_1^E - z_0^E \end{bmatrix} \quad (7)$$

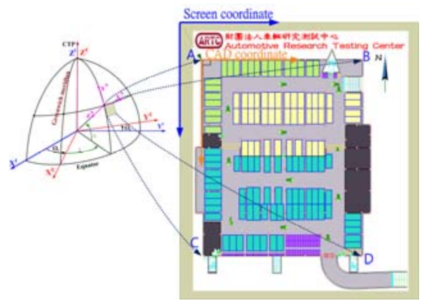

Fig. 8. GPS, GIS and screen coordinates relation.

IV. SYSTEM IMPLEMENTATION AND TESTS

The developed system is integrated and fabricated modular units based on the circuit configuration as Fig. 9. All the modules are available and ready to use. The implementation work needs to design suitable power supply; data interface and control circuit with accurate strategy to carry out the expected function capability. System software on data bus is programmed with appropriate protocol. Under the integrated concept, the proposed system will operate GPS data acquisition and INS correction to enhance the navigation performance. To accomplish the capability of VU, the odometry and gear-box speed are test and compared with GPS velocity in ARTC campus.

The odometry hardware used frequency to voltage chip to convert signals into voltage. The dynamic test is compared with GPS velocity. The odometry speed test is implemented in the ARTC campus, and operator drove to the road terminal and turn left/right. The odometry frequency of odometry signal was varying from 0 Hz to 600 Hz, and then converted to voltage (0.0~5.0V). In low speed operation, the odometry signal has large variation because of disturbance in Fig. 10. However, the mostly result is very similar to GPS velocity and this test is accomplished in calm weather. The right part of Fig. 10 is special used to test availability and know how the available speed is. The odometry sensor has high feasibility and could be used in vehicle test when the speed is larger than 10kph.

After INS had been set well in demonstrated vehicle, a driver drove in different speed to test straight moving and turn availability. The straight driving test is used to adjust accelerometer parameters refer to GPS speed. The output data would be processed using integration. Owing to integration error, the result should be calibrated and delicate processed well. The left part of Fig. 11 used a one-axis acceleration to get speed and the result is compared with GPS speed. The parameters was learned and calibrated by parameters learning and error cancelation. Hence, the speed error is under 5kph. In the similar way, the gyro integrated angular rate into heading comparing with GPS course w.r.t North direction in the right part of Fig. 11.

Fig. 9. The hardware of autonomous system in demonstrated vehicle.

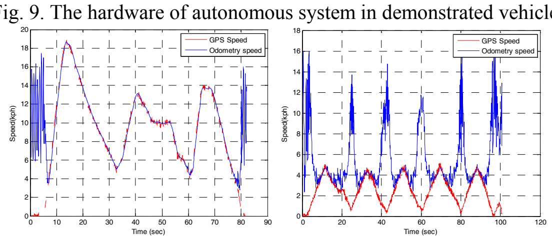

Fig. 10. Gearbox speed test from 0~20 and 0~5kph w.r.t GPS.

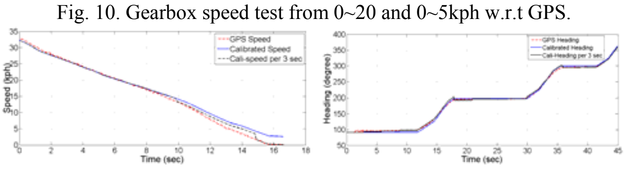

Fig. 11. Inertial sensor integration w.r.t GPS.

The proposed system is well integrated until unit tests and interface tests have been finished. In system operation, driver books a parking lot and drive to parking area. The booking information is demonstrated and operated in cell phone navigator. When vehicle passes through the parking entrance, the panel shows the booking location which DSRC transmits the on-line MAP in Fig. 12. Owing to the autonomous navigation characteristic of SmartValet, the Fig. 13 shows its availability in underground. The position is calculated from the integration of INS and VU data. The most special characteristic of SmartValet is on-line GIS correction which is demonstrated and calibrated by finger motion in Fig. 14. The clicking position of touch panel is onto screen coordinate which can convert to CAD coordinate using (7). The moving direction is the new heading which is calculated from NED coordinate variation. Although the driver drives in the parking underground, he/she can see the target location in touch panel. The integrated position error may increase with mean-square of time, but this problem can be easily solved with HMI interaction.

Fig. 12. Book a parking lot and drive to parking entrance.

Fig. 13. Autonomous Navigation in parking underground.

Fig. 14. On-line GIS correction.

V. Conclusion

This paper has successfully integrated with INS and vehicular information as autonomous navigation. Using the integrated algorithm to compute the inertial information, the vehicle track can be displayed on GIS. A parking service and information system is developed with 3G mobile network and DSRC communication. The capability of parking garage service system using sensor fusion is applied and verified. In the future, this system technology can provide a good business service from parking to shopping. This system has complete solutions from on-board unit to parking area management system. SmartValet can overcome all of the possible barriers, such as underground, multipath effect or shadowing.

In conclusion, the mainly contribution of this paper is to design a parking garage service system. The autonomous technology is applied, and the complicated HMI procedures have been test in demonstrated scenario. System unit test also presented the calibration importance, and the on-line GIS correction showed system innovation that driver could be have a friendly operation under proposed system concept.

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