A Location Method for Autonomous Vehicle Based on Integrated GPS/INS

Qingmei Yang, Jianmin Sun

Abstract—**The location system is a key technology of autonomous vehicle. Autonomous vehicle can sense all kinds of information and make decisions during moving out of door. The integrated GPS/INS location system of autonomous vehicle based on data fusion is studied in the paper. Based on the analysis of location methods, such as the global positioning system (GPS), inertial navigation system(INS), dead reckoning (DR) system and the vector electronic map, GPS and IMS are integrated in the location system of the autonomous vehicle. The GPS/INS integrated location system is designed. Kalman filter is used in the GPS subsystem and the IMS subsystem. Data of fusion of INS/GPS is simulated. The results of simulation show that the fusion location can improve the precision and reliability of the location system.**

I. INTRODUCTION

AUTONOMOUS vehicle has wide application foreground. It can be used in factory, military, farm, etc. Autonomous vehicle can sense all kinds of information on self and environment. Then it can make decisions to adjust or control self to fit the environment when it moves in and out of door. According to the planed target, it can finish path planning based on the known geographic information and environment information. Thus autonomous vehicle may move in planed trajectory to finish its task.

The location system is a key technology of autonomous vehicle. Every kind of location sensor has its individual advantages and disadvantages. Therefore, in actual location system, single location sensor is less used, contrarily, in order to provide more precise and reliable location information, two or much more different location sensors are often used altogether.

A location method based on data fusion of autonomous vehicle is studied in the paper. A GPS and INS integrated location system of autonomous vehicle is designed and simulated.

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Qingmei Yang is with College of Automation, Beijing Union University, Beijing 100101, P.R.China, (corresponding author, e-mail: yang_qm123@163.com).

Jianmin Sun is with School of Mechanical-electronic and Automobile Engineering, Beijing University of Civil Engineering and Architecture, Beijing 100044, P.R. China. (e-mail: jianminsun@ tom.com).

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II. DATA FUSION METHORDS

Data fusion techniques are widely used in many areas such as autonomous vehicle, tracking, surveillance systems, intelligent Robots, modern industry, as well as in applications where accuracy is of a main concern [1-3]. Data fusion is the process of combining data from several sources into a single unified description of a situation. A system employs multiple sensors when the single sensor system cannot provide satisfactory accuracy or reliability [4][5].

Data fusion refers to a wide range of information processing techniques and methodologies. It can educe the uncertainty in the value of a measured parameter and reduce the effect of measurement noise. Furthermore, data fusion can improve the precision and reliability of the measurement system.

Data fusion methods have many kinds, such as Bayes decision theory, D-S evidence theory, Kalman filter, fuzzy fusion and neural network fusion *etc*[6][7].

Bayesian Theory. We consider probabilistic and Bayesian fusion firstly. The degrees of belief are represented by probabilities (a prior, conditional and a posterior probability). Decisions are usually taken from a posterior probability. Suppose that H_1, $H_2 \cdots H_j$, represent mutually exhaustive hypotheses (i.e., the existence of an object of identity i) that can "explain" an event E (or datum, observable, and so on), which has just occurred. Then

$$P(H_j / E) = \frac{P(E / H_j)P(H_j)}{\sum_j P(E / H_j)P(H_j)} \tag{1}$$

$$\sum_j P(H_j) = 1 \tag{2}$$

where $P(H_j / E)$ is the posterior probability of hypothesis H_j being true (object *j* existing) given the evidence, $P(H_j)$ is a prior (and unconditional) probability of hypothesis H_j being true. $P(E / H_j)$ is the probability of observing evidence E given that H_j is true. In most studies about Bayesian theorem, some statistical parameters are also assumed to be know, namely the prior probabilities of the hypotheses.

Kalman Filter. Kalman filter is used to fuse dynamic sensor information in real time. The method decides the best fusion data estimate of statistical meaning with statistical recursive nature of measure model. If the system has linear dynamical model and the noise of system and sensor is white noise model with Gaussian distribution, Kalman filter can provide unique best estimate of statistical meaning. Kalman filter's recursive nature make the information processing system needn't large store and calculation cells. The data fusion of the location system commonly uses the Kalman filter.

Fuzzy inference. In the multi-sensor system, the environment information provided by each information source is uncertain in some level. The uncertain information fusion is a course of deducing uncertain in fact. Fuzzy logic can be used to fuse the information of graph analysis and object recognition. Fuzzy logic may directly express certainty of multi-sensor data fusion in the course of inference. If systemization method is used to establish model of uncertainty during data fusion, consistent fuzzy inference is generated.

III. THE DESIGN OF INTEGRATED GPS/INS LOCATION SYSTEM

Inertial Navigation System (INS) can provide the position and velocity of vehicles by integral of acceleration measured with accelerometers mounted on vehicles. It is independent of the geomagnetic field, electromagnetic radiation and other outside disturbances[8].

The Global Positioning System (GPS) can provide the vehicle's three-dimensional position, velocity information and time with consistently high precision over time. It has the advantages of all weather, globality and high precision. However GPS has limitations such as low sampling rate, and it is impossible to realize continuous localization by GPS in an urban area where the satellites signal is obstructed by tall buildings, trees and tunnels, etc [9][10] .

A. The Design of GPS Subsystem

The GPS subsystem consists of a GPS logger with Jupiter GPS receiver the data received from Jupiter GPS receiver include the latitude, longitude, velocity and the number of available satellites. A nine-state standard Kalman filter is employed to process GPS data for estimating the vehicle position and velocity. Estimate and covariance propagations are performed every update time, when a measurement data that consists of the latitude, longitude, velocity and the number of available satellites is received from GPS at a 1-Hz frequency. The measurement vector is chosen as $[v\ y\ x\ ]$ where x, y and v are, respectively, east position, north position and velocity received from GPS. And conventionally the state vector is chosen as $[s_x\ v_x\ a_x\ s_y\ v_y\ a_y\ v\ a\ \dot{a}]$, where s_x and s_y are respectively east and north positions, v_x and v_y are respectively the velocities along x and y axes, a_x and a_y are the accelerations along x and y axes respectively, v is the vehicle velocity, a is the vehicle acceleration and $\dot{a}$ is the first derivative of a . The state equation and measurement equation of the GPS subsystem are shown in formula (3) and formula (4).

$$\begin{bmatrix} s_x(k+1) \\ v_x(k+1) \\ a_x(k+1) \\ s_y(k+1) \\ v_y(k+1) \\ a_y(k+1) \\ v(k+1) \\ a(k+1) \\ \dot{a}(k+1) \end{bmatrix} = \begin{bmatrix} 1 & T & T^2/2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & T & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & T & T^2/2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & T & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & T & T^2/2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & T \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} s_x(k) \\ v_x(k) \\ a_x(k) \\ s_y(k) \\ v_y(k) \\ a_y(k) \\ v(k) \\ a(k) \\ \dot{a}(k) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ W_x(k) \\ 0 \\ 0 \\ W_y(k) \\ 0 \\ 0 \\ W_v(k) \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} x(k) \\ y(k) \\ v(k) \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} s_x(k) \\ v_x(k) \\ a_x(k) \\ s_y(k) \\ v_y(k) \\ a_y(k) \\ v(k) \\ a(k) \\ \dot{a}(k) \end{bmatrix} + \begin{bmatrix} V_x(k) \\ V_y(k) \\ V_v(k) \end{bmatrix} \tag{4}$$

Where T is 1 s, Wx (K), Wy (K) and Wv (K) are state white noise respectively and Vx (K), Vy (K) and Vv (K) are observation white noise respectively.

It is significant for the implementation of the real-time system of the improved Kalman filter to reduce the load of calculation. Therefore, such a high-order system can be converted into three parallel low-order subsystems to enhance the efficiency of calculation on the basis of the theory of decentralized filter. The GPS subsystem described by Equation (3) and (4) is decentralized into three independent subsystems. The state vector, system matrix and noise vector of Equation (3) is decentralized as:

$$X_x = \begin{bmatrix} s_x(k) \\ v_x(k) \\ a_x(k) \end{bmatrix} \quad X_y = \begin{bmatrix} s_y(k) \\ v_y(k) \\ a_y(k) \end{bmatrix} \quad X_v = \begin{bmatrix} v(k) \\ a(k) \\ \dot{a}(k) \end{bmatrix} \quad X = \begin{bmatrix} X_x \\ X_y \\ X_v \end{bmatrix} \tag{5}$$

The observation matrix in Equation (4) is decentralized as below:

$$H_x = H_y = H_v = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \tag{6a}$$

$$H = \begin{bmatrix} H_x & 0 & 0 \\ 0 & H_y & 0 \\ 0 & 0 & H_v \end{bmatrix} \tag{6b}$$

The decentralized filtering system can be shown in Equation (7). It can be used for real-time implementation of the GPS/INS integrated location system.

$$\begin{cases} X_x(k+1) = A_x X_x(k) + \omega_x(k) \\ x(k) = H_x X_x(k) + V_x(k) \end{cases}$$
$$\begin{cases} X_y(k+1) = A_y X_y(k) + \omega_y(k) \\ y(k) = H_y X_y(k) + V_y(k) \end{cases} \tag{7}$$
$$\begin{cases} X_v(k+1) = A_v X_v(k) + \omega_v(k) \\ v(k) = H_v X_v(k) + V_v(k) \end{cases}$$

Where

$$A_x = A_y = A_v = \begin{bmatrix} 1 & T & T^2/2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix} \tag{8}$$

$$\omega_y = \begin{bmatrix} 0 \\ 0 \\ W_y(k) \end{bmatrix} \qquad \omega_v = \begin{bmatrix} 0 \\ 0 \\ W_v(k) \end{bmatrix}$$

(9)

B. The Design of INS Subsystem

Although a GPS system has so many merits, the data could be poor when the satellites signals are obstructed by tall buildings, trees and tunnels, etc. To overcome such disadvantages, the IMS location system is integrated to improve the performance of system.

The IMS (Inertial Measurement System) consists of the accelerometers and gyros. The measurement data of the accelerometers and gyros to the INS filtering system, where temperature drifts, initial bias and random noise of inertial sensors are compensated by corresponding hardware and software.

The positioning errors of INS subsystem include the initial bias, temperature drift and random noise of the inertial measurement unit. The temperature drifts of inertial sensors are compensated by hardware. The initial bias of positioning errors needs to be processed by software. The random noise of positioning errors can be reduced by Kalman filter. Suppose the initial bias of positioning errors is zero, the state equation and observation equation of the INS subsystem is shown in equation (10) and (11).

$$\begin{bmatrix} x_i(k+1) \\ \dot{x}_i(k+1) \\ \ddot{x}_i(k+1) \\ y_i(k+1) \\ \dot{y}_i(k+1) \\ \ddot{y}_i(k+1) \\ \theta_i(k+1) \\ \dot{\theta}_i(k+1) \\ \ddot{\theta}_i(k+1) \end{bmatrix} = \begin{bmatrix} 1 & T_i & T_i^2/2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & T_i & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & T_i & T_i^2/2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & T_i & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & T_i & T_i^2/2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & T_i \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_i(k) \\ \dot{x}_i(k) \\ \ddot{x}_i(k) \\ y_i(k) \\ \dot{y}_i(k) \\ \ddot{y}_i(k) \\ \theta_i(k) \\ \dot{\theta}_i(k) \\ \ddot{\theta}_i(k) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ W_{ix}(k) \\ 0 \\ 0 \\ W_{iy}(k) \\ 0 \\ 0 \\ W_{i\theta}(k) \end{bmatrix} \tag{10}$$

7 $$\begin{bmatrix} \ddot{x}_{zi}(k) \\ \ddot{y}_{zi}(k) \\ \ddot{\theta}_{zi}(k) \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \ddot{x}_i(k) \\ \ddot{y}_i(k) \\ \ddot{\theta}_i(k) \end{bmatrix} + \begin{bmatrix} V_{xi}(k) \\ V_{yi}(k) \\ V_{\theta i}(k) \end{bmatrix} \tag{11}$$

Where x_i is east position, y_i is north position, $\dot{x}_i$ and $\dot{y}_i$ is the velocity along the x and y axes respectively, $\ddot{x}_i$ and $\ddot{y}_i$ is the acceleration along the x and y axes respectively, θ is the orientation angle, $\dot{\theta}$ and $\ddot{\theta}$ are angular rate and angular acceleration respectively. $\ddot{x}_{zi}(k)$, $\ddot{y}_{zi}(k)$ and $\ddot{\theta}_{zi}(k)$ are measure data of $\ddot{x}_i(k)$, $\ddot{y}_i(k)$ and $\ddot{\theta}_i(k)$ respectively. The Kalman filter of INS subsystem is used in the decentralized filtering system.

IV. Simulation Of Integrated Location System for Autonomous Vehicle

The GPS/INS integrated location system described here is a federal filtering system based on the theory of multi-sensor data fusion.

To improve location accuracy, a data fusion algorithm based on Kalman filter is used in the GPS/INS integrated location system. The state equation and measurement equation of data fusion algorithm is shown in formula (12) and (13). According to this method, the result of data fusion of different sensors is

$$X(k) = AX_f(k-1) + BU(k-1) + \Gamma W(k-1) \tag{12}$$
$$Z(k) = CX(k) + V(k) \tag{13}$$

Where *Z(k)*is data from GPS subsystem, *U(k)* is the data from INS subsystem.

The fusion location is simulated with Matlab. The results of simulation are shown in fig.1- fig.3. The results of simulation

show that the fusion location can improve the precision and reliability of the location system.

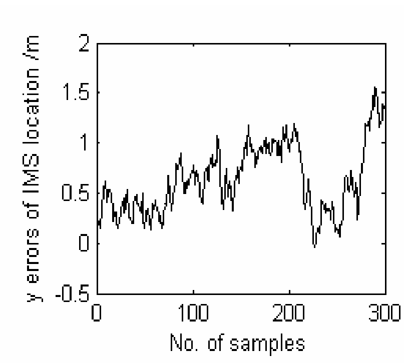

Fig.1 x derection errors of IMS location

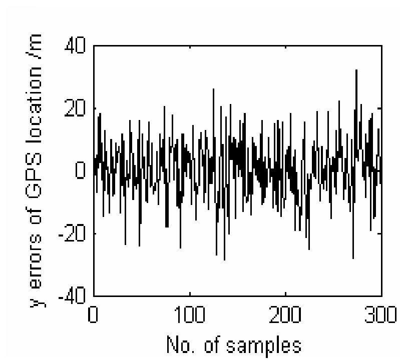

Fig.2 x derection errors of GPS location

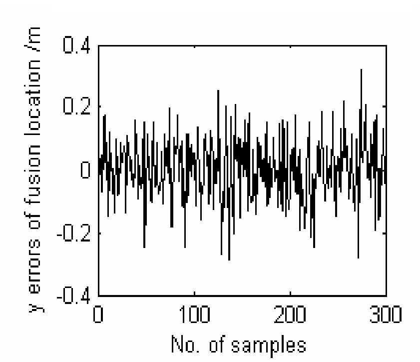

Fig.3 x derection errors of fusion location

V. CONCLUSION

In the paper, the location system of an autonomous vehicle is studied. The conclusions are shown as below:

(1) Based in the analysis of location methods, GPS and IMS are integrated in the location system of the autonomous vehicle.

(2) The GPS subsystem of the GPS/INS integrated location is designed.

(3) The IMS location subsystem of the GPS/INS integrated location is designed.

(4) The GPS/INS integrated location system is designed. Data of fusion of INS/GPS is simulated. The results of simulation show that the fusion location can improve the precision and reliability of the location system.

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