4S-Van Design for Application Environment

[1]Seung-Yong Lee, Seong-Baek Kim, and [2]Jong-Hun Lee
[1] Engineer, [2]Director
4S Integration Research Team / CSTL / ETRI

161, Kajong-Dong, Yusung-Gu, Daejon, 305-350
TEL : +82-42-860-1693
FAX : +82-42-860-4844
E-mail : {lsy9892,kimstar100, jong}@etri.re.kr

ABSTRACT

4S-Van is being developed in order to provide the spatial data rapidly and accurately. 4S-Van technique is a system for spatial data construction that is heart of 4S technique. Architecture of 4S-Van system consists of hardware integration part and post-processing part. Hardware part has GPS, INS, color CCD, camera, B/W CCD camera, infrared rays camera, and laser. Software part has GPS/INS integration algorithm, coordinate conversion, lens correction, camera orientation correction, and three dimension position production. In this paper, we suggest that adequate 4S-Van design is needed according to application environment from various test results.

Keywords : 4S, GPS/INS,CCD

1. INTRODUCTION

4S-Van technique is a system for spatial data construction that is heart of 4S(GNSS,GIS,ITS,SIIS) technique. It enables acquisition of the position information and accurate image data of the object by post processing. 4S-Van consists of two GPS, INS, two color CCD, camera, and two B/W CCD camera. Fig.1 shows the architecture of 4S-Van. GPS/INS decides position and attitude of various sensors that are attached to 4S-Van.

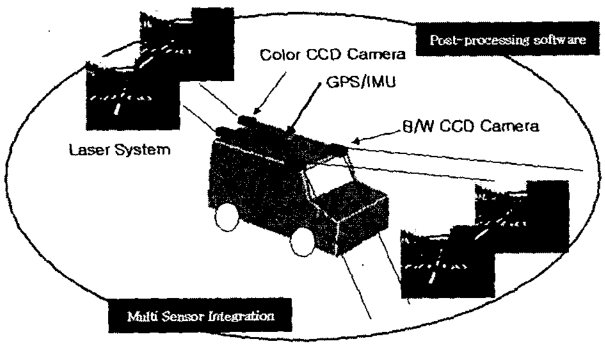

Fig 1. The architecture of 4S-Van

CCD camera acquires stereo image of the object and analyzes three-dimensional coordinates of various surrounding things that are included on stereo image, using GPS/IMU data and information of CCD camera. Post-processing part can integrate and process the data collected by each sensor. It consists of GPS/IMU integration algorithm, self-calibration, production of exterior orientation of CCD, and three-dimensional position calculation of object. In this paper, we discuss the design of 4S-Van using loosely-coupled GPS/INS method and self-calibration method.

The remainder of this paper is organized as follows. Chapter 2 provides calibration and orientation Production method of CCD camera. Chapter 3 describes a integrated method of GPS/INS. In Chapter 4, we show the result of performance of 4S-Van's each part. This paper concludes with a summary of our suggestions.

2. Calibration And Orientation Production Of CCD Camera

To get position of the object using CCD image, lens distortion correction, position and attitude data of camera are essential. In this paper, we define the lens distortion, orientation parameter(position and attitude of camera), focal length, and principal point by self-calibration method[8].

2.1 Self-calibration

Self-calibration method is process that adds lens distortion parameter of CCD camera in fundamental space intersection algorithm. That is, self-calibration uses exterior orientation as well as focal length, principal point, lens distortion parameter by unknown parameter and get solution by least square method. This method has advantage that it can get exterior orientation as well as focal length, principal point, and lens distortion. The numerical formula are

$$x' = x - x_p + dx_r \quad (2\text{-}1)$$

$$y' = y - y_p + dy_r \quad (2\text{-}2)$$

$$dx_r = (x - x_p)\frac{\Lambda r}{r} = (x - x_p)k_1 r^2 \quad (2\text{-}3)$$

$$dy_r = (y - y_p)\frac{\Lambda r}{r} = (y - y_p)k_1 r^2 \quad (2\text{-}4)$$

$$q = m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L) \quad (2\text{-}5)$$

$$r = m_{11}(X_A - X_L) + m_{12}(Y_A - Y_L) + m_{13}(Z_A - Z_L) \quad (2\text{-}6)$$

$$s = m_{21}(X_A - X_L) + m_{22}(Y_A - Y_L) + m_{23}(Z_A - Z_L) \quad (2\text{-}7)$$

where (x_p, y_p) are principal point, f is focal length, k_1 is distortion parameter, X_A, Y_A, Z_A are coordinates of camera position, and $m_{11} \sim m_{33}$ are elements rotation matrix.

2.2 Production of camera orientation of CCD Image

The camera orientation production of CCD image is process that calculates position and attitude of each CCD by combining position and attitude of CCD with GPS/INS data. Fig 2 shows flow diagram of exterior orientation data processing in our suggested system..

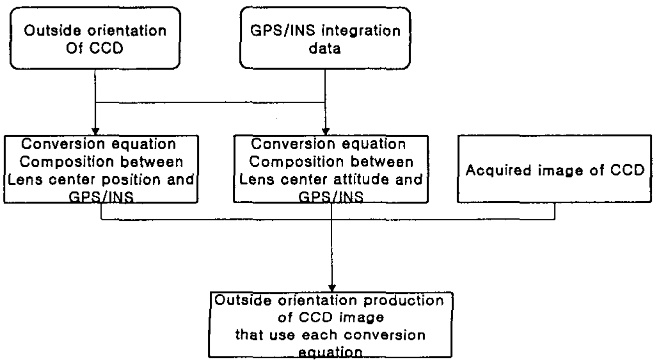

Fig 2. The architecture of 4S-Van

That is, we get exterior orientation of CCD camera in moving environment by combining GPS/INS data with object coordinates of camera position and attitude.

3. GPS/INS integration

While GPS provides position and velocity data with long-term stability, INS provides high-rate position and velocity data with short-term stability. By integrating the GPS with INS, an enhanced navigation system can be achieved to provide highly accurate navigation data. For the GPS/INS integration, there are required error model of INS and navigation equation[3][4].

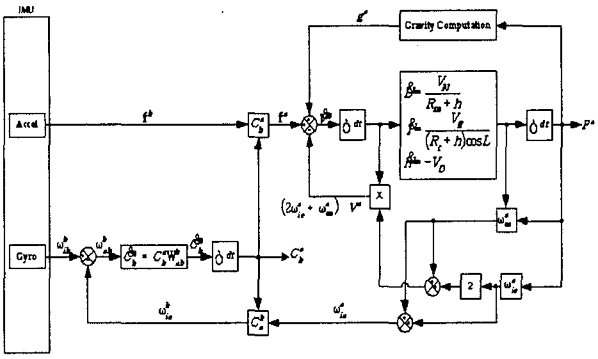

Fig 3. The architecture of strap-down INS

3.1 INS Navigation Equation

Strapdown INS Navigation algorithms consists of attitude, position, and velocity equation. Attitude algorithms are divided into quaternion update method, direction cosine matrix, and euler angle. In this paper, quaternion is used for obtaining an accurate and fast attitude of the vehicle. The velocity and position algorithm can be written as

$$\dot{v}^n = C_b^n f^b - (2w_{ie}^n + w_{en}^n) \times v^n + g^n \quad (3\text{-}1)$$

where C_b^n, g, f, and w are transformation matrix between body frame and navigation frame, normal gravity vector, specific force vector, and angular velocity vector respectively.

3.2 INS Error Model

The application of the Kalman filtering technique combining INS and the GPS requires mathematical error model of INS and GPS system. Several forms of

INS error models have been developed till present. It is proved that all these error models are actually equivalent and can be derived in a unified approach. In this paper, the following φ error model is applied.

$$\frac{d}{dt}\delta v^n = -\delta(w_{in}^n + w_{ie}^n)v^n - (w_{in}^n + w_{ie}^n)\delta v^n + \delta a^n + \frac{\partial g^n}{\partial p^n}\delta p^n + \delta g^n \quad (3\text{-}2)$$

$$\delta\varphi^n = -w_{in}^n \times \varphi^n - C_b^n \delta w_{ib}^b + \delta w_{in}^n \quad (3\text{-}3)$$

where a^n, p^n, v^n, φ^n are the acceleration error, position error, velocity error, and attitude error, respectively.

3.3 GPS/INS Integration Filter Design

The GPS/INS Integration system is usually configured in a tightly-coupled method or a loosely-coupled method. Specially, the loosely-coupled method has an advantage of simple structure and easy implementation.

There are two error calibration techniques for implementation of GPS/INS integration system: the feedforward method and feedback method. In this paper, loosely-coupled method is applied for the integration design, and feedback update technique is applied for the calibration of system errors[1][7]. The state equation of Integration Kalman filter are as

$$\dot{X} = FX + GW \quad (3\text{-}4)$$

$$F = \begin{pmatrix} F_{11} & F_{12} \\ 0_{9\times9} & 0_{9\times9} \end{pmatrix} \quad (3\text{-}5)$$

$$G = \begin{pmatrix} C_b^n & 0_{3\times3} \\ 0_{3\times3} & D^{-1}C_b^n \\ 0_{3\times3} & 0_{3\times3} \end{pmatrix} \quad (3\text{-}6)$$

where X is navigation error state, G is noise input matrix, W is zero-mean gaussian white noise; and the sub-matrices F_{11} and F_{12} are given by

$$F_{12} = \begin{pmatrix} C_s^n & 0_{3\times3} & 0_{3\times3} \\ 0_{3\times3} & D^{-1}C_s^c & D^{-1}C_s^n diag(a^s) \\ 0_{3\times3} & 0_{3\times3} & 0_{3\times3} \end{pmatrix} \quad (3\text{-}8)$$

The measurement equation is written as.

$$Z = Hx + V \quad (3\text{-}9)$$

where Z is input measurement of kalman filter, V is measurement noise, H is measurement matrix

$$H = \begin{pmatrix} O_{6\times3} & I_{6\times6} & O_{6\times9} \end{pmatrix} \quad (3\text{-}10)$$

4. Test Results

4.1 Self-Calibration

After establishing calibration target for Self-calibration test, we measured accurate position of each target by GPS and total station. Also, after measuring each target by 4S-Van, we processed measured data by self-calibration method. Finally, we compared acquired position by self-calibration with acquired position by total station, and verified performance of self-calibration method. The following tables are the results of self-calibration, where camera1 is left CCD camera and camera2 is right CCD camera of vehicle. Table 1 shows information about lens distortion and table 2 shows exterior orientation of CCD camera.

Table 1. The exterior orientation of CCD camera

	Camera 1	Camera 2
X(m)	-0.173586	-0.089520
Y(m)	0.601111	0.641841
Z(m)	3.789430	3.743983
Omega(rad)	-0.091472	-0.083936
Phi(rad)	-0.011572	-0.006811
Kappa(rad)	0.026546	0.029131

Table 2. Lens orientation

	Camera 1	Camera 2
Focus length(mm)	10.262043	9.698757
Principal point (mm)	-0.265375	-0.168290
Principal point(mm)	0.851428	0.988679
Radial distiortion	0.032464	0.030344

$$
F_{11} = \left(\begin{array}{c} -a \begin{array}{ccccccccc}
0 & -W_e \sin(\phi) & 0 & 0 & \cos(\phi) & 0 & -W_e \sin(\phi) & 0 & 0 \\
W_e \sin(\phi) & 0 & W_e \cos(\phi) & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & -W_e \cos(\phi) & 0 & 0 & -\sin(\phi) & 0 & -W_e \cos(\phi) & 0 & 0 \\
0 & \frac{-a^3}{r} & \frac{a_2}{r} & 0 & -W_e \sin(2\phi) & 0 & 0 & 0 & 0 \\
\frac{a_3}{r\cos(\phi)} & 0 & \frac{-a_1}{r\cos(\phi)} & 2W_e \tan(\phi) & 0 & \frac{-2W_e}{r} & 0 & 0 & 0 \\
a_2 & -a_1 & 0 & 0 & 2rW_e \cos^2 \phi & 0 & 0 & 0 & 0
\end{array} \\
\begin{array}{ccc} O_{3\times3} & I(3) & O_{3\times3} \end{array}
\end{array} \right) \quad (3\text{-}7)
$$

Table 3 shows the position difference of acquired position by self-calibration and acquired position by total station.

Table 3.The position of space intersection method

ID	X direction(m)	Y direction(m)	Z direction(m)
1	0.004053	0.004312	0.031481
2	5.42E-05	0.003528	0.004697
3	0.001119	0.00351	0.023237
4	0.001813	0.004768	0.013425
5	0.005952	0.006996	0.037186
6	0.004135	0.001589	0.005886
7	0.001084	0.000977	0.002902
8	0.000385	0.000376	0.008664
9	0.000524	0.001428	0.014051
10	0.00048	0.001388	0.003367
11	0.004258	0.002381	0.014304
12	0.008252	0.000754	0.014575
13	0.003917	0.002351	0.000894
14	0.000479	0.006771	0.019897
15	0.000139	0.004408	0.008875
16	0.000777	0.005016	0.011781
17	0.006791	0.001328	0.018483
18	0.011233	0.004792	0.029572
19	0.004481	0.006791	0.015324
20	0.001793	0.010541	0.028265
21	0.00098	0.012508	0.03561
22	0.00075	0.009179	0.021573
23	0.00156	0.009673	0.030194
24	0.001088	0.013069	0.032637
25	0.003018	0.005431	0.008492
26	0.012624	0.006161	0.026908
(RMSE)	0.019223		

4.2 GPS/INS Integration

This paper uses a crossbow's INS, VG600CA, low cost INS with three fog gyros and three accelerometers. INS has gyro biases of around 0.03 degree per second and accelerometer biases of around 8.5mg. In order to test performance of GPS/INS Integration algorithm, we experimented by two methods. One is matlab simulation and the other is vehicle test. Matlab simulation was done to evaluate the designed integration algorithm performance in computer. Also, we attached GPS/INS on roof of vehicle for vehicle test. Fig. 4 and Fig. 5 show simulation results, and Fig. 6 and Fig. 7 show vehicle test results.

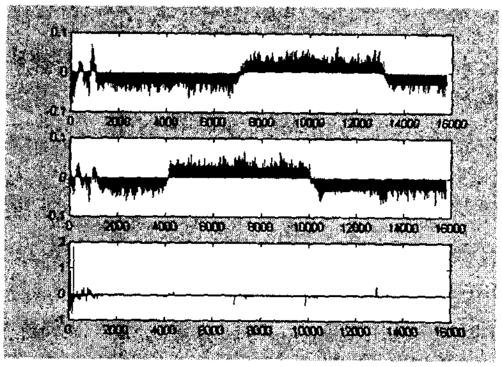

Fig 4. The attitude error of simulation

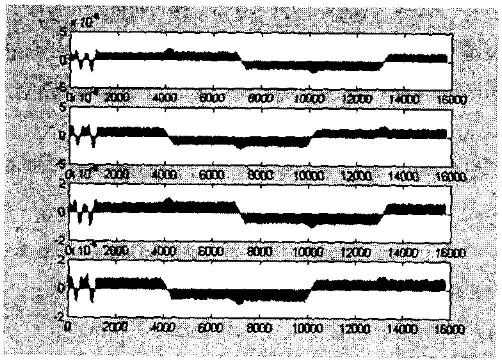

Fig 5. The velocity and position error of simulation

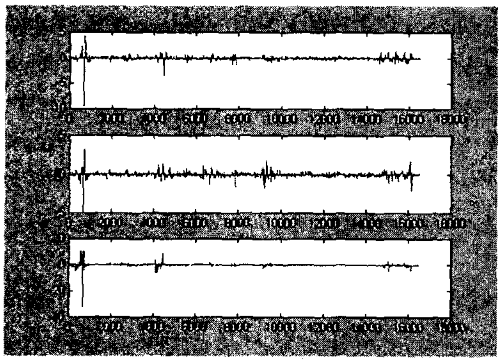

Fig 6. The attitude error of vehicle test

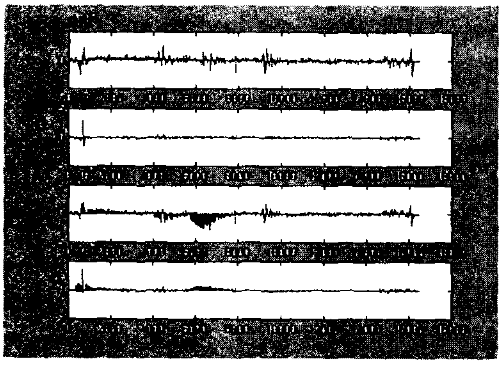

Fig 7. The velocity and position error of vehicle test

In the test results, simulation data error is smaller than vehicle test error. But both results don't meet final performance requirement of 4S-Van.

5. Conclusion

In this paper, we suggest the design of 4S-Van using GPS/INS loosely-coupled integration and self-calibration algorithm. GPS/INS loosely-coupled integration provides position and attitude data of moving vehicle, and self-calibration algorithm provides position, attitude, and lens error correction data of CCD camera. The performance of the 4S-Van's each part is evaluated through the computer simulation and the vehicle tests. Test results show that the integrated GPS/INS yields better accuracy than stand-alone GPS or INS. Also, the result of self-calibration method shows error within 0.05m that could presume final error of 4S-Van. we find that better INS is required to get satisfactory result.

As a further study, tightly-coupled method should be considered to achieve better accuracy under dynamic environment, synchronization between GPS/INS and CCD camera, and error correction method by sensor integration.

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