개선된 GPS 항법 알고리듬의 실시간 처리 주행 실험결과

원종훈*, 고선준*, 이자성**
* 아주대학교 대학원 제어계측공학과, ** 아주대학교 전자공학부

Field Test Results of the Improved GPS Navigation Algorithm

J .H. Won*, S. J. Ko*, J. S. Lee**
* Dept. of Control & Instrumentation Eng. Ajou Univ., ** School of Electronic Eng. Ajou Univ.

Abstract - This paper presents the results of the field of an improved GPS navigation algorithm. The improved GPS navigation algorithm is a modified Kalman filter which is designed to be ideally suited to car navigation in urban area where lack of GPS visibility is the major problem because of the frequent blockage of the GPS signals by tall buildings and other structures. The method allows the user to estimate its position when the number of visible GPS satellites becomes less than four by using altitude fixing and clock bias estimation techniques. The two estimation techniques are integrated with the Kalman filter in a mutually compensating manner and it is shown that the 3-dimensional position accuracy is well maintained when the number of the visible satellites drops down to two for a reasonable period of time. The post processing results are included to show the improved performance of the modified algorithm over a normal conventional GPS Kalman filter.

1. Introduction

Land vehicle navigation systems have become versatile with the emergence of the Global Positioning System(GPS) introduced to commercially available automobile navigaion systems in eary 1990s. But the operational use of the GPS in car navigation is limited by the characteristics of irregular car dynamics and frequent signal blockages by tall buildings and other structures in urban areas. A number of techniques based on algorithmic methods such as altitude fixing, clock bias fixing, and, quasi-pseudorange method, have been developed to overcome the above mentioned problems. These methods allow users to estimate its position with three visible satellites for a reasonable period of time with moderate error degradation. These methods, however, can not be applicable when the number of visible satellites become less than three which frequently occur in urban areas. other solutions integrate GPS with compensatory navigation systems such as Dead Reckoning System(DR) or Inertial Navigation System(INS). The integrated GPS/DR(or INS) system has good performance. It needs additional hardware and cost[1]. The previous researches in Ref. 2, show that the intelligent mixing of the altitude fixing and the clock bias estimate techniques can be efficiently used to maintain the accuracy with the navigation system base on a low cost GPS C/A code receiver.

In this paper, the modified Kalman filter algorithm based on the results in Ref. 2 is implemented in the on-board GPS receiver with the real time processing software and tested in the real urban road.

2. GPS Navigation

As is well known, the positioning with GPS requires at least four visible GPS satellites[3]. The measurement of range to the satellites, made by the receiver with an imprecise clock, is called "Pseudo-range" because it contains a bias of fixed magnitude in each range estimate due to the clock error. The pseudo-range is defined by

$$PR_i = R_i + B + E_i \qquad \text{for } i=1,2,3,4 \tag{1}$$

$$R_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} \tag{2}$$

where

PR_i : pseudo-range to the i-th GPS satellite

R_i : true range the i-th GPS satellite

B : clock bias(m)

E_i : range error

(x_i, y_i, z_i): i-th GPS satellite's position(ECEF)

(x, y, z): user's position(ECEF)

One of the methods that solve the above nonlinear navigation equation is iterative least-square estimation technique which is a mathematical and statistical technique for dealing with nonlinear and redundant observations. The iterative least-square estimation technique has some shortcomings: i.e., it requires the initial value and needs more computational time and memories. Koch algorithm is a deterministic solution method which is efficient in terms of computational time and memory consumption[4]. But Koch algorithm can only be applicable to the four visible satellite case. These two methods are instantaneous solution algorithm which uses only instant range informations. Kalman filter is an another alternative for solving the equation in a sequential manner. Kalman filter updates the navigation states by using the system dynamics and the measurement nois statistics. It also allows user to estimate its position and clock bias states by propagating state variables without receiving pseudorange measurements. However, the propagation error usually grows rapidly without proper compensation.

3. Altitude Setting and Clock Bias Estimation Techniques

The change of position in vertical direction of a ground vehicle can usually be assumed to be small and often negligible. After the number of visible satellites drops down to three, this assumption make it possible for user to continue to estimate navigational solutions by using the previous estimate of altitude. The measurement equations can be modified when only three visible satellites are available as follows:

$$y_i = R_i + B + E_i \qquad \text{for } i=1,2,3 \tag{3}$$

$$y_4 = D = R_4 + E_4 \tag{4}$$

where

$R_4 = \sqrt{x^2+y^2+z^2}$: the range from the center of the earth to receiver

$D = \sqrt{x_{-1}^2+y_{-1}^2+z_{-1}^2}$: the altitude estimate from previous information

E_4 : the altitude estimate error

(x_{-1}, y_{-1}, z_{-1}) : the position estimate at previous time

Three-satellite GPS navigation can also be accomplished by equipping the user with a precise clock[5]. But, the unstability characteristics of crystal oscillator installed in general low cost C/A code GPS receiver limits its use to the three-satellite GPS navigation. The required stability of the clock is a function of the maximum allowable PDOP and the time interval between updates of the clock. But for a reasonable time interval, the clock bias can be estimated within moderate error bounds by utilizing the trend of its error which can be modeled by a second order equation with frequency offset and frequency drift[6].

$$B(t) = B_0 + B_1(t-t_0) + \frac{1}{2}B_2(t-t_2)^2 + \varepsilon(t), \quad (t > t_0) \tag{5}$$

where

$B(t)$: the clock bias estimate at time t

B_0 : the clock bias at time t_0

B_1 : the clock bias rate at time t_0

B_2 : the drift of clock bias rate at time at t_0

$\varepsilon(t)$: the estimate error at time t

t_0 : the last updating time

By using the clock bias estimate obtained from previous updates, we can reduce one additional unknown, namely, B in Equation (1).

4. Design of the Modified Kalman Filter

The altitude setting method and the clock bias estimation technique can be integrated into Kalman filter in a mutually compensating manner to enhance the navigation performance and allow continuous navigation when the GPS satellites are blocked frequenty as in urban environment.

Where four or more satellites are visible, the normal Kalman filter is used to estimate navigational solution and to obtain altitude and clock bias parameters[7].

In case of three visible satellites, the measurement equation is modified as follows.

$$PR_i = R_i + B + E_i \qquad \text{for } i=1,2,3 \tag{6}$$

$$PR_4 = D + \hat{B} + E_i \tag{7}$$

where D is the altitude estimate at previous time and $\hat{B}$ is the clock bias propagation of Kalman filter.

When only two satellites are visible, the measurement equation is modified as follows.

$$PR_i - \hat{B} = R_i + E_i \qquad \text{for } i=1,2 \tag{8}$$

$$D = R_3 + E_3 \tag{9}$$

where $\hat{B}$ is the clock bias estimate obtained through propagation without updating. In Equation (8), measurement is treated as the true range from receiver to satellite: i.e., the clock bias is not unknown variable. Therefore, the Kalman filter can be modified to a six states filter excluding clock bias and clock bias rate. The modified system dynamics equation is given by

$$\underline{X}'(k+1) = F' \cdot \underline{X}'(k) + \underline{w}'(k) \tag{10}$$

where

$$\underline{X}' = [x, y, z, \dot{x}, \dot{y}, \dot{z}]^T$$

$$F' = \begin{bmatrix} 1 & 0 & 0 & T & 0 & 0 \\ 0 & 1 & 0 & 0 & T & 0 \\ 0 & 0 & 1 & 0 & 0 & T \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The modified measurement equation and direction cosine matrix are given by.

$$y_i'(k) = R_i(k) = g_i'(\underline{X}(k)) + v'(k) \tag{11}$$

$$H = \frac{\partial \hat{g}_i}{\partial \underline{X}} = \left[-\frac{x_i - x}{R_i}, -\frac{y_i - y}{R_i}, -\frac{z_i - z}{R_i}, 0, 0, 0\right] \tag{12}$$

the more detailed description about the modified Kalman filter is presented in reference [2].

5. Field Test Results

The proposed algorithm was applied to raw data received by a low cost GPS receiver(Trimble SVee-6) mounted on a car. The raw data was recorded every 0.5 second and applied to the various algorithms to compare their performance with same raw data. The Diffential GPS method was chosen to reduce the positioning error and ensure the accuracy of the estimate of altitude and clock bias estimate. The reference receiver(Motolora OnCore) was placed at known point on the top of building where the signal blockage did not occur. The route of a car was selected around the Ajou university where the visibility problem frequently occured. The positioning output was presented in a bit map to compare the accuracies of the algorithms.

In Fig. 1 and Fig. 2, the number of visible satellite and relative positions of the GPS satellites with respect to the car during test run are shown respectively. The positioning output of Koch algorithm in stand alone mode is shown in Fig. 3. As can be seen, the trajectory of a car is often out of the road due to errors such as SA, ionospheric disturbance, etc.. Fig. 4 and Fig. 5 show the positioning of Koch algorithm and conventional Kalman filter when DGPS method was applied, respectively. We can see in these figures that the position accuracy is sufficiently improved to locate the position of a car on the road but the lack of visibility remains a problem which induces the discrepancy of the trajectory in Koch algorithm and the growth of positioning error in conventional Kalman filter. Fig. 6 is the result of improved Kalman filter algorithm by utilizing the altitude and clock bias estimate technique discussed in section 4. As can be seen, the trajectory of a car is continuous and smooth because the improved algorithm makes it possible for a user to keep obtaining its position with moderate error when the lack of GPS visibility occurs.

The proposed algorithm was also implemented and tested in real time software for applying to the GPS receiver which was developed in the previous reseach[8]. The developed hardware is based on the chip sets of GEC-Plessey. The real time test result of the improved algorithm without DGPS is shown in Fig. 7. The algorithm is based on the real time DGPS which needs the communication links between the moving and the reference receivers because its position accuracy is very sensitive to the accuracy of the altitude and clock bias estimate. In this case, the improved algorithm is applied to when the number of visible satellite is more than three because of no use of DGPS.

6. Conclusion

The improved GPS positioning algorithm has been derived and implemented to overcome the problem of lack of the number of visible satellites in urban area. The performance of the algorithm has been demonstrated by field tests and was compared with the performance of the conventional Kalman filter. The results indicate that the improvement is made without any extra cost because this algorithm needs no additional hardware.

[Reference]

[1] B. W. Parkinson and J. J. Spilker Jr.(ed.), ***Global Positioning System: Theory and Applications***, Vol. I, AIAA, Washington, DC., 1996, pp.409-483.

[2] J. H. Won, Improved GPS Algorithms for Car Navigation in Urban Environment with Limited GPS Visibility, M.S. Degree Thesis, Ajou University, Korea, Feb., 1997.

[3] R. J. Milliken, C. J. Zoller, "Principle of Operation of NAVSTAR and System Characteristics," *Global Positioning System, Vol. I, The Institute of Navigation*, pp.3-14, 1980.

[4] J. S. Lee, "Principle and Simulation of GPS Relative Navigation," Internal Letter No. D/794-400-81-039, Rockwell International Corporation, 1981.

[5] M. A. Sturza, "GPS Navigation Using Three Satellites and A Precise Clock," *Global Positioning System, Vol. II, The Institute of Navigation*, pp.122-132, 1984.

[6] P. Misra, M. Pratt, "Role of the Clock in a GPS Navigation Receiver", MIT, Lincoln Lab, 1995.

[7] R. G. Brown, P. Y. C. Hwang, ***Introduction to Random Signals and Applied Kalman Filtering***, John Wiley & Sons Inc., 1992, pp.409-455.

[8] 이자성, 원종훈, 고선준, "GPS 수신기 개발에 관한 연구," 태양 CNS 위탁과제, 아주대학교 전자공학부, 1998, 3.

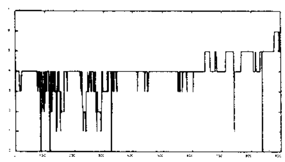

Fig. 1. Number of visible satellite

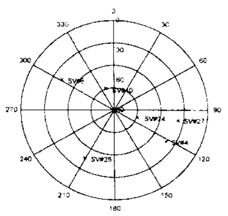

Fig. 2. Relative positions of the GPS satellites with respect to the car

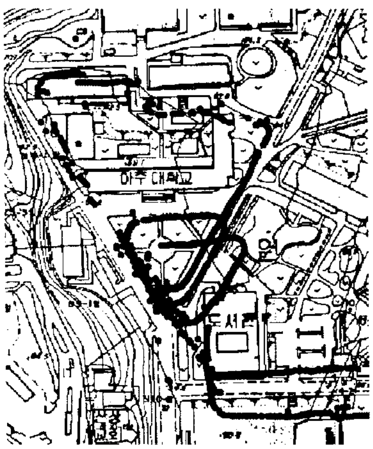

Fig. 3. Positioning of Koch algorithm (stand alone, post-processing)

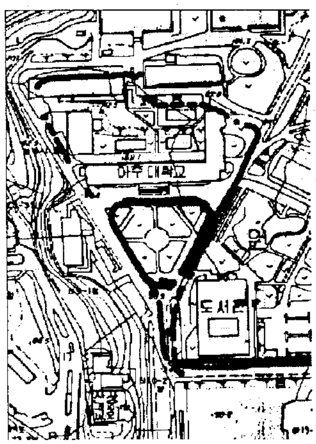

Fig. 4. Positioning of Koch algorithm (DGPS, post-processing)

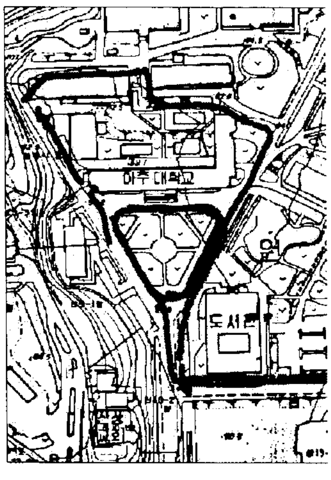

Fig. 5. Positioning of normal Kalman filter (DGPS, post-processing)

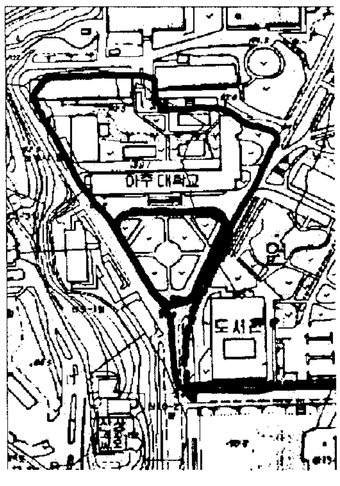

Fig. 6. Positioning of the modified Kalman filter (DGPS, post-processing)

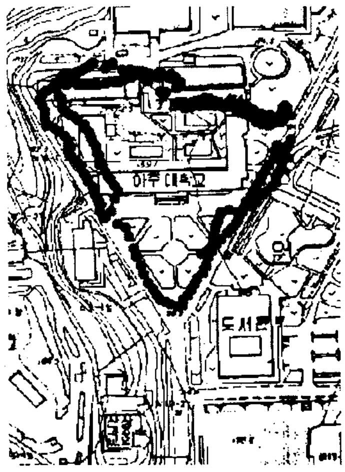

Fig. 7. Positioning of the modified Kalman filter(stand alone, real time processing)