Development of Linearly Interpolated PRC Regenerating Algorithm to Improve Navigation Solution using Multi-DGPS Reference Stations

Kyung Ryooh Oh *, Jong Chul Kim **, and Gi Wook Nam ***
* Department of avionics, Korea Aerospace Research Institute, Rep. of Korea
(Tel : +82-42-860-2825; E-mail: bigoh@kari.re.kr)
**Department of Mechanical Engineering, Japan University, Tokyo, Japan
(Tel : +82-42-860-2340; E-mail: jckim@kari.re.kr)
*** Department of avionics, Korea Aerospace Research Institute, Rep. of Korea
(Tel : +82-42-860-2365; E-mail: gwnam@kari.re.kr)

Abstract: In this paper, the linearly interpolated PRC(Pseudo Range Correction) regenerating algorithm was applied to improve the DGPS(Differential Global Positioning System) positioning accuracy at user's spot by using the various PRC information obtained from multi-DGPS reference stations.

The PRC information of each GPS satellite is not varying rapidly; it is possible to assume that the variation of PRC information of each GPS satellite is linear. So the linearly interpolated PRC regenerating algorithm can be applied to improve the DGPS positioning accuracy at user's spot by using the various PRC information obtained from multi-DGPS reference stations.

To test the performance of the linearly interpolated PRC regenerating algorithm, maritime DGPS reference stations’ PRC data was used in RTCM format. 11 maritime DGPS reference stations are in service providing DGPS information to public since 1999. Two set of 3 DGPS reference stations are selected to compare the performance of the linearly interpolated PRC regenerating algorithm. The DGPS positioning accuracy was dramatically improved about 40%.

Linearly interpolated PRC regenerating algorithm adopted multi-channel DGPS receiver will be developed in near future.

Keywords: DGPS, Multi-DGPS station, weighting coefficients, PRC, RRC, linearly interpolated PRC generating algorithm

1. INTRODUCTION

Since 1994, Korea Aerospace Research Institute has been conducting the research on the GBAS (Ground Based Augmentation System) for precision approach and landing of aircraft based upon the concept of CNS/ATM (Communication Navigation Surveillance/Air Traffic Management). As the results of above the research, Korea Government has a plan to install GBAS on each domestic airport for the safety of civil airlines. If the Government’s plan is implemented, around the metropolitan area, especially around Seoul, multi-GBAS environment will be established considering the minimum GBAS service coverage as 30NM (Nautical Mile).

The PRC information of each GPS satellite is not varying rapidly; it is possible to assume that the variation of PRC information of each GPS satellite is linear. So the linearly interpolated PRC regenerating algorithm can be applied to improve the DGPS positioning accuracy at user's spot by using the various PRC information obtained from multi-DGPS reference stations.

The user’s position can be calculated from the regenerated PRC which can be expressed as the linear combination of multi-DGPS reference station’s known position and PRC values of common satellite from multi-DGPS reference stations.

To test the performance of the linearly interpolated PRC regenerating algorithm, maritime DGPS reference stations’ PRC data was used in RTCM format. 11 maritime DGPS reference stations and 1 inland DGPS reference station are in service since 1999. Two set of 3 DGPS reference stations are selected to compare the performance of the linearly interpolated PRC regenerating algorithm. The DGPS positioning accuracy was dramatically improved about 40%.

Even though common PRC was extracted from RTCM format, the suggested PRC regenerating algorithm in this paper can be applied to improve the DGPS positioning accuracy in GBAS for civil aviation.

Just change the navigation solution software of GBAS receiver, GBAS positioning accuracy improvement is expected without any modification of GBAS reference station’s equipment.

Linearly interpolated PRC regenerating algorithm adopted multi-channel DGPS receiver will be developed in near future.

2. MARITIME DGPS REFERENCE STATINS IN KOREA

Korean Government (Ministry of Maritime Affairs and Fisheries) has started DGPS service from 1999 by the IMO (International Maritime Organization) recommendation of using GNSS in maritime navigation.

MOMAF extended its DGPS infra structure into the inland to establish nationwide DGPS system by 2005 or 2006. [1, 2]

![Maritime DGPS reference stations in Korea (Jun. 2004)](image-url)
3. NAVIGATION SOLUTION USING MULTI DGPS INFORMATION

Due to the characteristics of GBAS (Ground Based Augmentation System), somewhat extensive network of DGPS reference stations need to be established. In the GBAS coverage, it is possible to receive valid corrections from a number of stations. Within a multiple DGPS reference station, solution all pseudo-range corrections received from pre-selected reference stations are used to position the mobile station. There are a number of different approaches to provide such a solution. [3]

Position domain approach (left of Fig 3): This is the simplest approach which computes an independent position using each reference station that corrections are received from. The resultant positions are later combined by taking a weighted average.

Centroid approach (middle of Fig 3): The pseudo-range corrections from all reference stations are combined to form one correction for each satellite in view. This correction should fit the centroid of the area defined by the reference stations that are used. Additional directional corrections can also be developed by examining the correlation between the composite centroid corrections and those at particular reference stations. The pseudo-range corrections for the centroid can be generated either at a land-based hub or at the mobile station itself. The advantage of the former is that the mobile station needs only to receive one set of pseudo-range corrections.

All-in-view approach (right of Fig 3): All the pseudo-range corrections received from the reference stations are incorporated into one positioning solution with no pre-processing (except for validity checks). For instance, the correction for satellite PRN 12 may be received from 4 different reference stations and will be used separately to correct the pseudo-range observed at the mobile station from PRN 12 - thus adding 4 observations to the system.

3.1 Developing Linearly Interpolated PRC Regenerating Algorithm

To developing linearly interpolated PRC regenerating algorithm, there are basic assumptions:

a. The user only uses the common in view satellites to calculate his position for both sides of user and reference stations.
b. At least, 4 common satellites exist between the user and reference stations.
c. The variation of the correction data of a satellite is small to assume that the characteristic of variation of PRC of each satellite is linear.

PRC linear interpolating Algorithm:

In the Fig. 4, the user stands at user1 or user2, 3 location between DGPS reference station\_1 and station\_n. The DGPS correction(PR\_X\_i, PR\_Y\_i, i=1,2,...,n) value of common satellite is not same, so there is a gradient of the DGPS correction value of common satellite between DGPS reference stations. If the user can use this gradient information, more precise position information can be achievable. [4]

The unknown user’s position (longitude, latitude) can be calculated from the regenerated PRC which can be expressed as the linear combination of multi-DGPS reference station’s known positions and PRC values of common satellite from multi-DGPS reference stations.

The unknown user’s position can be expressed by using the relative geometry information of the stations. [5]
Let’s assume that the number of reference stations is $r$, marks as $n_r$, and number of satellite in line of sight is $s$, marks as $n_s$. And every each reference stations observe same GNSS satellites, but the PRC values of specific satellite are differ from each other DGPS reference stations. Then the linearly interpolated $\text{PRC} (V^i_j = V^i_1 + a_1^i(x_j - x_1) + a_2^i(y_j - y_1))$ at user’s spot the PRC what we want can be expressed as Eq.4.

$$V^i_j = V^i_1 + a_1^i(x_j - x_1) + a_2^i(y_j - y_1)$$

In the above equation, $x_i$ is the latitude $y_i$ is longitude respectively in WGS-84. The parameters $a_1^i$ and $a_2^i$ are the coefficients of a plane which contains all DGPS reference stations coordinates.

For the case of using 3 DGPS reference stations information, Eq.4 can be written as matrix format:

$$\begin{bmatrix} V^i_2 - V^i_1 \\ V^i_3 - V^i_1 \end{bmatrix} = \begin{bmatrix} \Delta x_2 \\ \Delta x_3 \\ \Delta x_3 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_2 \end{bmatrix}$$

Or,

$$\begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = \left( \begin{bmatrix} \Delta x_2 \\ \Delta x_3 \\ \Delta x_3 \end{bmatrix} \right)^{-1} \begin{bmatrix} V^i_2 - V^i_1 \\ V^i_3 - V^i_1 \end{bmatrix}$$

Where $\Delta x_j = x_j - x_1$, $\Delta y_j = y_j - y_1$

For the case of using more than 4 DGPS reference stations information above equations can be written as in general format: [5]

$$\begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = (G^T G)^{-1} G^T \begin{bmatrix} V^i_2 - V^i_1 \\ V^i_3 - V^i_1 \\ V^i_4 - V^i_1 \\ \vdots \\ V^i_r - V^i_1 \end{bmatrix}$$

Where $G = \begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \\ x_4 & y_4 \\ \vdots \\ x_r & y_r \end{bmatrix}$

Matrix $G$ is a set of known information. After get $a_1$ and $a_2$ by Eq.7, linearly interpolated PRC ($V^i_j$) can be achieved in Eq.4.

![Fig.6 Functional diagram of extracting common PRC](image)

**Generating linearly interpolated PRC**

In Fig. 6, GPS time in GPS raw data and Modified Z count in DGPS information are compared to check the data is time synchronized each other or not. If data is time synchronized each other, and then checks the common satellite number in data from Reference Stations. If the number of common satellite is less than 4, the data will be discarded and the next epoch data will be used.

If more than 4 common DGPS data exist, the procedure moves to next step. To get the linearly interpolated PRC information, input the user’s position into the linearly interpolated PRC regenerating algorithm. Then PRC linear interpolating algorithm will regenerate the new PRC value.

The next procedure to get DGPS position is explained in Fig.7. In this procedure, the number of common satellite is critical. If the common satellite number is more than 4, the regenerated PRC will input into the DGPS navigation solution algorithm based on the carrier smoothed algorithm. (See Fig. 8)
3.2 Analysis the Effect of Linearly Interpolated PRC

To analyze the effect of linearly interpolated PRC algorithm, three set of DGPS reference stations combination used. There are 4 DGPS reference stations in first set, 3 in second set, 2 in third set.

As a result, second set shows best results. Comparing the position accuracy with stand alone DGPS reference station, 33% improved on an average. Table 1 shows the results of analysis of the three set of DGPS reference stations.

In the case of using 2 DGPS reference stations’ PRC information, the DGPS position accuracy was 1.8m. Other case of using 3 DGPS reference stations’ PRC information, the DGPS positioning was 0.788m and 1.164m depending on which combination of DGPS reference stations used. The last case of using 4 DGPS reference stations’ PRC information, the worst result achieved. DGPS position accuracy was 2.449m.

<table>
<thead>
<tr>
<th>Multi Ref.</th>
<th>Changgi got</th>
<th>Ochong do</th>
<th>Sochong do</th>
<th>Chumun jin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>202km</td>
<td>127km</td>
<td>279km</td>
<td>214km</td>
</tr>
<tr>
<td>Position Error</td>
<td>1.164m</td>
<td>1.959m</td>
<td>1.607m</td>
<td>1.223m</td>
</tr>
<tr>
<td>Improve ment</td>
<td>41.0%</td>
<td>40.6%</td>
<td>27.6%</td>
<td>4.8%</td>
</tr>
</tbody>
</table>

Table 1 The position accuracy using 3 DGPS reference stations

![Fig. 9 Selecting DGPS Ref.s Functional diagram of generating linearly interpolated PRC](image1)

![Fig. 10 Single Ref.s DGPS positioning accuracy (Sochongdo)](image2)

Position accuracy 1.223 m

![Fig. 11 Single Ref.s DGPS positioning accuracy (Ochongdo)](image3)

Position accuracy 1.607 m
4. CONCLUSION AND FUTURE WORK

The suggested linearly interpolated PRC regenerating algorithm in this paper, improve the DGPS position accuracy about 40% without any changes in DGPS reference station’s system. In this study off-lined PRC data was used. If RF signal directly from the DGPS stations can be available, more improvement will be expected. In near future, the performance of suggested regenerating PRC algorithm will be evaluated with 3ch DGPS receiver.

ACKNOWLEDGMENTS

This work was supported by the 2004 National R&D Program. The authors greatly appreciate the support of Korea Research Council of Public Science & Technology (KORP), Korea.

REFERENCES