A GPS Based Navigation Aid for the Blind

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Abstract

In this paper we present development of the GPS based navigation aid for blind. That aid utilizes inverse DGPS positioning module which, along with other benefits for the blind user, enables implementation of more complex navigation algorithms. In particular, we have implemented DGPS algorithm augmented by altitude data available from digital map. This solution improved the availability of positioning by more that 23% and its accuracy by more than 15%. All the results were experimentally verified.

1 INTRODUCTION

A navigation system for blind and visually impaired pedestrians is being developed in the Electronic System and Information Technology Research Group, at Brunel University [1] with the main aim to increase their mobility. The main positioning module utilizes a Differential Global Positioning System (DGPS), which is the Global Positioning System (GPS) operated in a differential mode, in order to provide more acceptable positioning accuracy for the blind user [2][3].

Both GPS and DGPS, however, share the same problem of insufficient availability in signal-blocked environments [4]. In urban canyon areas, the availability and accuracy of GPS can be degraded due to blocking of the satellite signals. More precisely, during the normal GPS receiver operation, pseudo-ranges from at least four GPS satellites are needed to solve the equations for the receiver's antenna position because of the four unknowns: three position unknown x, y and z and the receiver's clock bias Δt [5]. If less than four satellites are available, or the geometry of satellites is poor, the GPS positioning error rapidly increases.

In this paper we present solution, which increases both the GPS positioning accuracy and availability. We have implemented inverse DGPS algorithm which, because of its centralized architecture, allows for more complex navigational algorithms to be used. In particular, it is two-dimensional (2-D) DGPS algorithm supplemented with altitude data available from map datasets replacing pseudo-range from one GPS satellite. Consequently, DGPS navigation solution requires pseudoranges from only three satellites to be available, hence increasing the positioning availability for more than 20%. Alternatively, when more than four satellites are available, the positioning processor can select only those three satellites that will yield the best possible navigation solution, hence increasing the position accuracy [5].

2 DESCRIPTION OF THE SYSTEM

The Brunel Navigation System for the Blind is based on inverse DGPS positioning with mobile unit and stationary base station, namely navigation center, linked using cellular mobile network, as shown in Fig. 1. Pseudo-range measurements from the GPS receiver placed within mobile unit is sent via general packet radio service (GPRS) terminal of the mobile phone to the navigation center. The base station calculates position offset using DGPS correction, which is either generated by the stationary GPS receiver with its antenna position surveyed with an accuracy of better than 0.5 m or received from a commercial provider through UHF radio link. The base station also calculates the position using altitude information retrieved from digital datasets (digital map). The position of the user is then graphically displayed on the digital map, which is then used by the operator to provide navigational information in a form of spoken messages transferred to the user via GSM communication channel.

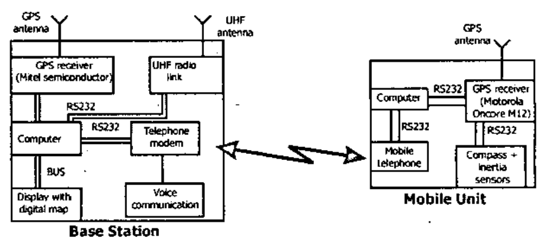

Fig. 1. Brunel inverse DGPS system

Along with better positioning accuracy and availability, such a configuration entails additional benefits to the users. Placing the entire responsibility of operating and maintaining the system with a sighted operator in the navigation centre minimizes the level of mental demand imposed on the user during navigation procces. Additionally, availability of the remote sighted guide reduces the travel related stress experienced by the visually impaired pedestrians in the same way as the real sighted guide, still allowing for considerably higher level of journey independence.

3 INVERSE DGPS ALGORITHM

The GPS receiver in the mobile unit uses pseudorange measurements PRM to each satellite, corrected by ionosphere and troposphere corrections ATM calculated by using standard single frequency models [6]. This data is then sent to the base station where pseudorange measurements are corrected using DGPS pseudorange correction PRC for each satellite as:

$$PRD_j = PRM_j + PRC_j \tag{1}$$

where PRD_j is the corrected pseudorange measurements for j-th satellite.

To determine the user position in three dimensions $u = (x, y, z)$ and the receiver clock offset t, pseudorange measurements are made to four satellites, which results in four equations with four unknowns x, y, z and t of the following form;

$$PRD_j = \left|\mathbf{s}_j - \mathbf{u}_{DGPS}\right| + ct_{DGPS} \tag{2}$$

where $j = 1-4$ indicates the j-th satellite, $\mathbf{s}_j$ is the position of the j-th satellite at the time the pseudorange measurement was taken, $\mathbf{u}_{DGPS}$ is a DGPS position solution, c is the speed of light and t_{DGPS} is a GPS receiver clock offset. The DGPS position is then calculated using linear approximation [7], which results in the following set of linear equations:

$$\Delta\boldsymbol{\rho} = \mathbf{H}\Delta\mathbf{u}_{DGPS-GPS} \tag{3}$$

$$\Delta\mathbf{u}_{DGPS-GPS} = \mathbf{H}^{-1}\Delta\boldsymbol{\rho} \tag{4}$$

where $\Delta\mathbf{u}_{DGPS-GPS}$ is a vector between the DGPS and GPS position solution, $\mathbf{H}$ is a cosine direction matrix and

$$\Delta\boldsymbol{\rho} = \begin{bmatrix} \Delta\rho_1 \\ \Delta\rho_2 \\ \Delta\rho_3 \\ \Delta\rho_4 \end{bmatrix} = \begin{bmatrix} ATM_1 - PRC_1 \\ ATM_2 - PRC_2 \\ ATM_3 - PRC_3 \\ ATM_4 - PRC_4 \end{bmatrix} \tag{5}$$

If the PRC_j correction value for the j-th satellite is not available, it is assigned to be ATM_j, hence providing $\Delta\rho_j = ATM_j - PRC_j = 0$.

In order to minimize the error contribution using redundant measurements to more than four satellites, which results in an overdetermined solution set of equations, the position calculation can be processed by least square estimation techniques, which leads to the solution [7];

$$\Delta\mathbf{u}_{DGPS-GPS} = \left(\mathbf{H}^T\mathbf{H}\right)^{-1}\mathbf{H}^T\Delta\boldsymbol{\rho} \tag{6}$$

However, if only three pseudorange measurements to different satellites are available, then the system of equations (2) is under-determined, and only solution to two dimensional positioning is available. If range measurement from additional sensor or source is available that is exactly in the vertical direction relative to the earth surface, this is then equivalent to having a satellite at the centre of the Earth [8] hence still enabling 3-D positioning. This range measurement is effectively a distance from the centre of the Earth to the user's antenna, the data that is available from the map dataset. Then the fourth equation in the system of equations (2) takes the form

$$\left|\hat{\mathbf{u}}_{DGPS} - c_s\right| = \left|c_s - \mathbf{u}_{DGPS}\right| \tag{7}$$

where $\hat{\mathbf{u}} = \left(\hat{u}_x, \hat{u}_y, \hat{u}_z\right)$ is the estimated initial user position and c_s is the centre of the sphere representing the altitude aiding equation. For simplicity, further in this paper we will denote this method simply as 2-D solution. However, the shape of the Earth is not spherical; instead elliptical WGS-84 model is used. To correct for this difference, we placed the centre of the sphere at the centre of the ellipsoid. The sphere radius was the distance between the centre and the predicted point location. We used computer simulation and changed the position of the point on the sphere within the distance of $\pm$ 100m. Observing the maximum distance from the sphere over the reference WGS-84 ellipsoid we found that for the point with the latitude 45^0 N, longitude 0^0, which is the most inaccurate scenario, the change from the assumed distance was not more than 0.4 m.

4 RESULTS

For the experimental verification of the developed inverse DGPS algorithm and altitude augmentation we used system shown in Fig. 1 and the Land-Form PROFILE map in 1:10,000 scale from Ordinance Survey. The high accuracy of this map dataset depends on the nature of the ground and is typically better than the half of the vertical interval of the source contour data, which is either 5 or 10 m.

For the purpose of accuracy measurement the person with mobile unit walked along the marked route. The route was carefully selected to simulate a 'typical' urban area with parts where signals from the satellites are very likely to be blocked. Some points along the route were surveyed with accuracy better than 1 m. Those points were used for calculation of the accuracy of the system. In order to account for different constellation of GPS satellites, the experiments were repeated four times at different time of the day.

Along with the accuracy measurements, we have also assessed the availability of the positioning. The positioning service was considered available when GPS receiver tracked at least 4 satellites for 3-D type of positioning solution or when using at least 3 satellites for 2-D type of solution. The elevation mask was set up to 5^0 as a commonly used value for performance assessment [5]. In all the experiments, the threshold for the dilution parameter was set up to 5 for Horizontal Dilution of Precision (HDOP). Selecting this value should maintain the horizontal accuracy of 30 m and 20 m for GPS and DGPS systems through 95% of the time.

The accuracy was expressed using the most commonly used accuracy measures:

- RMS – the square root of the average of the squared errors;

- CEP – a circle's radius centered at the true position and containing 50% of the points in the horizontal scattered plot;
- R95 - a circle's radius centered at the true position and containing 95% of the points in the horizontal scattered plot.

For the reason of comparison, all the experiments were carried out with the system operating in both GPS and DGPS mode.

Fig. 2 shows typical experimental results plotted on the corresponding Ordinance Survey Land-Line. The reference path obtained from surveying points coincides with the true walking path on the map within 0.5 m.

Table 1 summarizes results of the assessment of the accuracy when both 2-D and 3-D positioning were available. It becomes apparent that 2-D positioning always gives better accuracy in both GPS and DGPS modes for at least 15% This is primarily due to the fact that the 2-D algorithm has higher number of options in selecting the best positioning solution (see equation (6)).

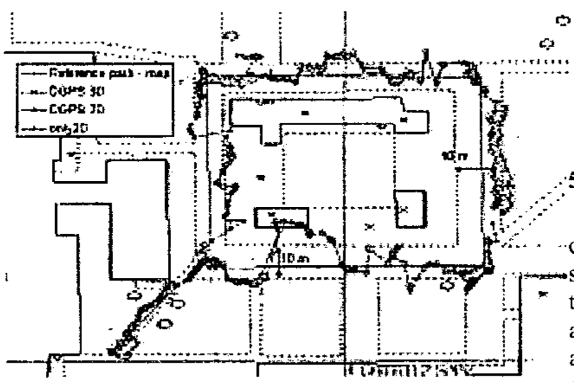

Fig. 2. The results plotted on the map

Accuracy of 2-D positioning when 3-D positioning was not available are shown in Table 2. It is apparent that positioning accuracy maintained the level of the accuracy of that when 3-D positioning was available.

Table 1 The comparison of the accuracy for 2-D and 3-D positioning

	Accuracy [m]		
	RMS	CEP	R95
3-D GPS	7.1	5.1	13.0
2-D GPS	6.1	4.5	11.5
3-D DGPS	6.0	3.4	12.7
2-D DGPS	5.1	3.2	9.7

Availability of the service plotted against the value of HDOP for both 2-D and 3-D positioning solution are shown in Fig. 3. It becomes apparent the difference in availability of 2-D and 3-D service is significant: 2-D service is improves the availability for more than 23%, from 63% to 86%. This is expected having in mind higher number of satellites available for 2-D solution.

Table 2 The comparison of the accuracy for 2-D and 3-D positioning

	Accuracy [m]		
	RMS	CEP	R95
2-D GPS	7.8	4.6	16.8
2-D DGPS	6.0	3.7	11.3

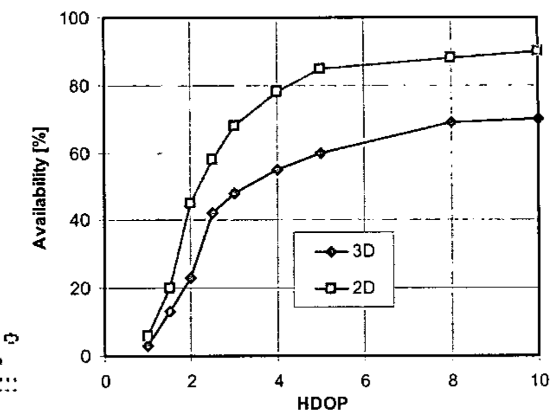

Fig. 3. Service availability

5 CONCLUSION

Performance of the GPS and DGPS positioning can be significantly degraded due to the blockage of signals from the satellites. Inverse DGPS configuration offers an efficient solution to improve both the accuracy and availability of the positioning as it enables implementation more complex navigational algorithms. It is also apparent that the navigation augmented with altitude data from map datasets increases the positioning accuracy for 15%, and positioning availability for at least 23%.

6 REFERENCES

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