ENHANCEMENT OF LOCAL AREA DGPS ACCURACY: A COMPOSITE APPROACH

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Abstract

In a conventional Local Area DGPS (LADGPS) operation, the user's receiver (rover) is set to receive signals from a nearest beacon (base) that provides signals meeting the appropriate standard, with the second-nearest acting as alternate. The reason for choosing the nearest beacon is that the accuracy of fixes (i.e. the position of user) is dominated by spatial dilution of precision (DOP) of the corrections. The degree of dilution increases with the distance of the rover from the base. In other words, the accuracy of the single base LADGPS service degrades as the users move away from the beacon. This is the major drawback of a single base LADGPS system. This paper attempts to highlight an approach that is being studied to minimize the spatial errors in the LADGPS system, hence enhancing the positioning accuracy provided by the service.

Keywords: *Local Area DGPS, DGPS Accuracy, GNSS Radio beacon, GNSS augmentation system*

1.0 INTRODUCTION

The growing demand for reliable and safe navigational system has forced many countries to establish appropriate Global Navigation Satellite System (GNSS) augmentation systems in their own territories. As far as marine applications are concerned, Differential GPS (DGPS) system has been widely adopted as a cost-effective land-based GNSS augmentation system. That is why many countries in the world have already invested in establishing DGPS systems. The United State of America, for instance, has established a large scale DGPS known as Nationwide DGPS (NDGPS) to provide the DGPS service to coast and coastal areas of the country (Wolfe et al, 2000; Allen, 1997). Similar trend in the Europe where there were 162 DGPS systems installed by the end of the year 2001. With those systems, all critical coastal areas have been served by at least two DGPS stations. The present trend shows that the DGPS may replace completely the old radio navigational systems including the Loran-C in the near future (Robert et al, 2001; Last et al , 2002). A quite similar trend can be seen in many parts of the world such as Australia, Japan, and South Korea.

Based on similar demand for an effective and safe navigational system in Malaysian waters, Malaysian government has already established several DGPS systems as part of the whole system known as SISstem PELayaran SATelit (SISPELSAT). Since the service coverage of the SISPELSAT is limited to 250 km from the base, the system is generally refer to a local system and it is known as a Local Area DGPS (LADGPS).

The paper reviews the basic aspect of a LADGPS and tries to highlight an approach that is being studied to enhance the LADGPS positioning accuracy especially in the Equatorial region where the atmospheric activities are quite active throughout the year.

2.0 THE BASIC ARCHITECTURE OF A LOCAL AREA DGPS

Figure 1-1 illustrates a basic architecture of a LADGPS. The base station, B consists of a Reference Station (RS) and a radio transmitter. At the RS, the true (geometric) range of each satellite is computed using satellite ephemeris while its corresponding observed range is recorded from measurement. By comparing the two ranges, the pseudo range corrections (PRC) for that particular ranges are determined. These PRCs together with other parameters are then channeled to the radio transmitter to broadcast them to the rover station. At the rover, the corrections are used to correct the observed ranges, and then use the corrected ranges for calculating its position.

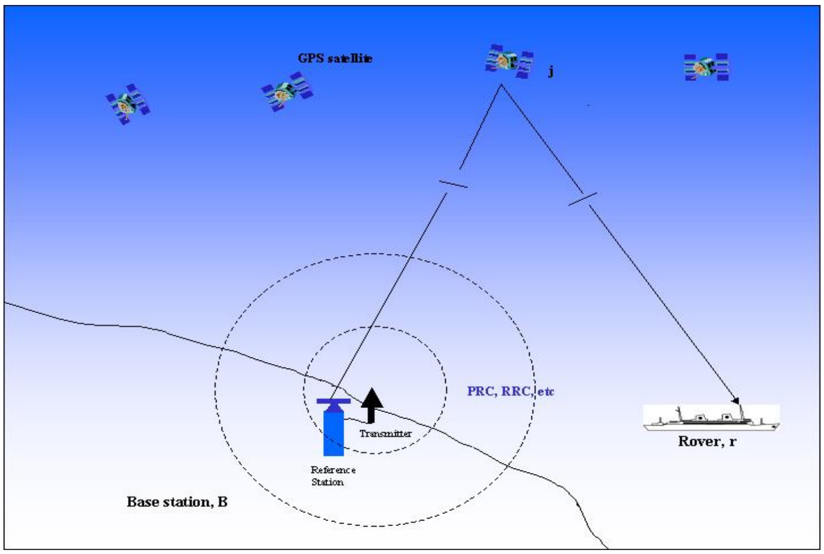

Figure 1-1: An Architecture of A Single Base LADGPS System

The stated strategy is known as the method of range correction or the measurement domain differential (Drane and Rizos, 1998). The mathematical aspect of the method of range correction is further discussed.

The observation equation for satellite j is given by (Misra and Enge, 2001, Hofmann-Welenhof et al, 2001):

$$R^j_B(t_o) = \rho^j_B(t_o) + \Delta\rho^j_B(t_o) + c\delta^j(t_o) - c\delta_B(t_o) \quad \ldots\ldots(1.1)$$

where $R^j_B(t_o)$ is the pseudorange observable for satellite j, $\rho^j_B(t_o)$ is the geometric distance from satellite j to base site B, $\Delta\rho^j_B(t_o)$ is the bias observable caused by the propagation route, $c\delta^j(t_o)$ is the bias observable caused by satellite, and $c\delta_B(t_o)$ is the bias observable caused by the receiver and its ground environment, c is the speed of light and t_o is the receiving time at the base. The geometric distance from the satellite, j to the base, B can be expressed as

$$\rho^j_B(t_o) = [(X^j(t_o) - X_B)^2 + (Y^j(t_o) - Y_B)^2 + (Z^j(t_o) - Z_B)^2]^{1/2} \quad \ldots\ldots(1.2)$$

where $[X^j(t_o), Y^j(t_o), Z^j(t_o)]$ are the WGS84 coordinates of satellite j at the epoch (t_o) (computed from broadcast ephemeris parameters in navigation file), and $[X_B, Y_B, Z_B]$ are the WGS84 coordinates of the base (surveyed point). Thus, the geometric range is a known value if both the satellite and the base are known. Hence, the pseudorange correction, PRC will be

$$PRC^j_B(t_o) = -R^j_B(t_o) + \rho^j_B(t_o) \ldots\ldots(1.3)$$

This is the amount of error that is transmitted to the rover. The derivative of PRC with respect to time is called Range Rate Correction, RRC

$$RRC^{j}_{B}(t_o) = [\partial\, PRC(t)/ \partial t\,]_{to} \qquad (1.4)$$

So, PRC at time t will be

$$PRC^{j}_{B}(t) = PRC^{j}(t_o) + RRC^{j}(t_o)\,(t - t_o) \qquad (1.5)$$

where $(t - t_o)$ is defined as latency. Adapting equation (1.1), the observation equation at rover, r, at time t will be

$$R^{j}_{r}(t) = \rho^{j}_{r}(t) + \Delta\rho^{j}_{r}(t) + c\delta^{j}(t) - c\delta_{r}(t) \qquad (1.6)$$

Practically, the rover is a mobile station. Then all right side terms of (1.6) are unknowns or not observed. That is why we need to utilise correction from the base to obtain corrected range at rover. It can be expressed as

$$R^{j}_{r}(t)_{corr} = R^{j}_{r}(t) + PRC^{j}_{B}(t) \qquad (1.7)$$

Inserting (1.5) into (1.7), we get

$$R^{j}_{r}(t)_{corr} = R^{j}_{r}(t) + PRC^{j}(t_o) + RRC^{j}_{B}(t_o)\,(t - t_o) \qquad (1.8)$$

Equation (1.8) is the current algorithmn used by a LADGPS system. It clears that the corrected ranges at the rover which are used to compute the rover's position, are combination of the observed ranges at the rover and the pseudorange corrections (PRCs) received from a base station. According to Enge et al (1992), the use of PRCs could improve the accuracy of GPS single frequency positioning from 100 meter to 2-8 meter. This level of accuracy is enough for many marine and land applications such as navigation and route guidance, automated vehicle tracking, emergency response, and others. However, some applications such as narrow water navigating, collision avoidance, and train control need better accuracy, between 1 to 2 meters (FRP, 1999).

One way of improving the accuracy as well as integrity of LADGPS is to apply multiple base system. As reported by Last et al (2002), PRCs calculated by interpolating the values from three stations at ranges of approximately 200-400 km from the receiver were more accurate than the PRCs from any single station.

For a developing country such as Malaysia, the use of multiple base station is limited because of limited number of GNSS radio beacons. Presently, Malaysia have only four GNSS radio beacon stations, two in Peninsular and the other two in East Malaysia. In Peninsular Malaysia, a station is establised at Kuantan, Pahang and the other one is at Lumut, Perak to provide LADGPS services to the east coast and west coast of Peninsular Malaysia respectively. The nominal range coverage of both stations is 250 km @ signal strength 37.5 dbμV (Department of Marine, 2004). Meanwhile, in East Malaysia, a station is establised at Kuching and the other is at Bintulu. The nominal range of both stations is 450 km @ signal strength 40 dbμV (Akob, 1996).

3.0 THE DRAWBACK OF THE PRESENT LADGPS SYSTEM

In the earlier section, we have seen that the pseudoranges at the rover are corrected using the received PRCs from the base. In normal practice, the PRCs are generated based on the atmospheric parameters recorded at the base. Generally, the errors of the received PRCs by the user's receiver are classified into two categories, namely, temporal and spatial. Temporal errors are varying with time, meanwhile spatial errors are varying with the baseline distance, i.e. the distance between the base and the user's receiver.

In the context of temporal errors, latency that is the time taken for the PRCs to travel from the base to user's receiver is significant to be considered. That is why the range rate correction (RRC) information is sent to users to compensate the time latency Generally, if the baseline distance is short, latency is small. The mobile users have to continuosly receive PRCs as frequently as possible, normally within seconds, to use them for DGPS solution.

Simply, if the distance between the base and the rover is not too large, say, less than 100 km, the conditions at the base and the rover are generally assumed to be identical. Spatially, they are correlated. It is purely based on this assumption, then the rover can utilise the PRCs that are received from the base for calculating its position and obtaining higher accuracy. Otherwise, the PRCs from the base become are no longer representative of the 'actual' PRCs for the user's receiver. In other words, the received PRCs are biased and using them for calculating positions will produce biased positions. This is the major drawback of the single base LADGPS system (Last et al, 2002; Cannon et al, 2002; Retscher et al, 2000; Van Essen et al, 1997; Morgan-Owen et al, 1995).

4.0 ENHANCING LADGPS ACCURACY

As stated earlier, with the termination of SA, atmospheric errors are the major sources of LADGPS errors. The significant atmospheric component is the ionosphere. Misra and Enge (2001) stated that ionospheric component of the propagation error can be highly variable depending upon the user's location, satellite elevation angle, and state of the medium. The user's location with respect to the base, either along meridian or any other direction will determine the amount of spatial decorelation due to ionospheric error. The size of error is more pronounced for users southward or northward of the base station because that the direction of higher ionospheric activity variation rate.

The ionospheric propagation error in the equatorial region or at higher latitudes may double for a single frequency receiver during high solar activity. The level of ionospheric effect to GPS signal propagation can be known from Total Electron Content (TEC) measurement. In the case on Peninsular Malaysia, studied the relative TEC during the geomagnetic storm of July 15-17, 2000 shown that the TEC values were variable ranging about –20% to 25% (Zain et al, 2002). Kamarudin et al (2003) studied TEC for the whole Peninsular Malaysia, latitude ranged from 1° North to 7° North, found that the values of TEC at Arau, Perlis (northern part) and Johor Bharu (southern part) ranged from 80 to 200 TECU. For this amount of TECs, the equivalent error in ranges if using a single frequency L1 GPS receiver would be 13 to 33 meters [1] .

According to Orpen and Zwaan (2001), LADGPS services in the equatorial and higher latitude regions may experience positioning errors up to 10 to 20 meters for a baseline a few hundred kilometers. Camargo et al (2000) reported that error reductions of 80% for point positioning and 50% for relative positioning of a baseline of approximately 100 km, were recorded when the data was processed with and

[1] Note: 1 TECU = 10^{16} electron per meter^2 = 0.163 meters of range error at L1.

without ionospheric corrections. The results gave a strong indication that ionosphere is a significance source of point positioning error for a single frequency receiver in the equatorial environment.

Moreover, the satellite elevation angle will correspond to the signal propagation path. Satellite at 5° elevation will yield delay three time higher than the vertical delay. Meanwhile, the state of medium is a function of time, day, season of the year. Generally, the local ionospheric activity is maximum at about 14.00 (local time) daily, and this will cause larger ionospheric delay and hence creates larger spatial decorelation. In constrast, the ionospheric activity is minimum during night, then the amount of delay is minimum. In most cases, geodetic GPS receivers employ mathematical models (generally the Klobucahar model) to correct for the ionospheric delay. However, most marine receivers do not compensate it (Moore and Hill, 2001).

The second significant atmospheric component is troposphere. The decorrelation of tropospheric errors is mainly due to the difference on the metereological parameters of the tropospheric layer through with GPS signals propagate from a satellite to a base and a rover. The effects are quite significant when the baseline is large and the altitude of the base and the user's receiver is different significantly. This is quite important especially when the LADGPS service is to be used for land navigation. Many base stations are located at the low altitude, e.g. near shore whereas the land navigators can be at any altitude.

Therefore, it is believed that a practical approach to enhance DGPS accuracy at the user's station is to minimise the effect of amospheric propagation at the station. This can be done if we can model the possible errors especially the effect of ionosphere and troposphere correctly.

Referring back to equation (1.8), by inserting equations (1.6) into it, the corrected range at the rover can be expressed as

$$\begin{aligned} R^j_r(t)_{corr} &= [\rho^j{}_r(t) + \Delta\rho^j{}_r(t) + c\delta^j(t) - c\delta_r(t)] + [PRC^j(t_o) + RRC^j(t_o)(t - t_o)] \\ &= [\rho^j{}_r(t) + \Delta\rho^j{}_r(t) + c\delta^j(t) - c\delta_r(t)] + [-\Delta\rho^j{}_B(t_o) - c\delta^j(t_o) \\ &\quad + c\delta_B(t_o) + RRC^j(t_o)(t - t_o)] \qquad \ldots\ldots(1.9) \end{aligned}$$

If we consider a limited duration, PRCs can be considered as time-invariant (i.e. $t = t_o$), so, the simplified term for equation (1.9) will be

$$R^j_r(t)_{corr} = \rho^j{}_r(t) + [\Delta\rho^j{}_r(t) - \Delta\rho^j{}_B(t)] - [c\delta_r(t) - c\delta_B(t)] \quad \ldots\ldots(1.10)$$

Normally, for a small or limited area, the assumption is that a strong correlation
between $\Delta\rho^j{}_r(t)$ and $\Delta\rho^j{}_B(t)$, therefore eq (1.9) becomes

$$R^j_r(t)_{corr} = \rho^j{}_r(t) + c\delta_B(t) - c\delta_r(t) \quad \ldots\ldots(1.11)$$

But for the equatorial region, the above assumption will not always truly present since the atmosphere is active throughout the year and can reach maximum level during the peak of 11 year solar cycle (Wanniger et al, 1991, 1993; and Campos et al., 1993 cited in Camargo et al (2000). So, the condition at the base and the rover are not really correlated, and creates a differential range error between base and rover which can be expressed as

$$\Delta\rho^j{}_{Br}(t) = \Delta\rho^j{}_r(t) - \Delta\rho^j{}_B(t) \quad \ldots\ldots(1.12)$$

This term could be modelled if the difference of atmosphere conditions at site B and rover, r are known. Hence, taking into account the above term, the equation (1.10) becomes

$$R^j_r(t)_{corr} = \rho^j_r(t) - c\delta_r(t) + c\delta_B(t) + \Delta\rho^j_{Br}(t) \quad (1.13)$$

Assuming the site B (beacon station) is equipped with a choke ring antenna and raised at a substantial height, as preventive measure to reduce multipath effect, then $c\delta_B(t)$ is negligible. So,

$$R^j_r(t)_{corr} = \rho^j_r(t) - c\delta_r(t) + \Delta\rho^j_{Br}(t) \quad (1.14)$$

where $c\delta_r(t)$ is mainly error from multipathing at the rover receiver. So, if we can model the third term of the above equation correctly based on local atmospheric conditions, then we will be able to enhance the rover positioning accuracy. However, equation (1.14) can be considered as a theoretical expression since true ranges are unmeasureable. A more practical approach is as the following.

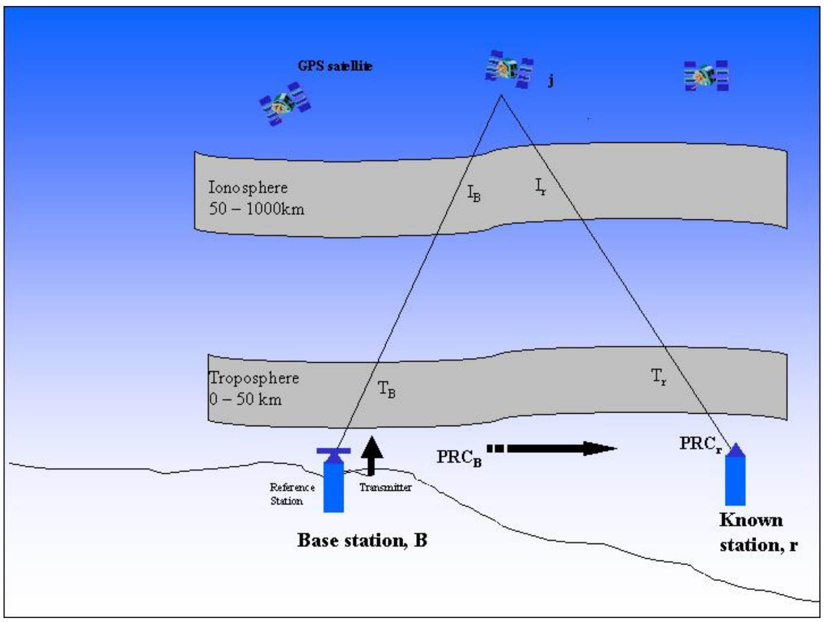

Figure 3-1: The layers of ionosphere and troposphere through which GPS signals propagate from satellite to base, B and user's receiver station (rover), r.

Refering to Figure 3-1, the ionospheric and troposheric effects on signals to the base and the user's are not the same due to different ionopheric as well as troposheric conditions, then $PRC^j_B(t)$ is not equal to $PRC^j_r(t)$. So, the different in PRCs can be expressed as

$$\Delta PRC^j_{Br}(t) = PRC^j_r(t) - PRC^j_B(t) \quad (1.15)$$

Then the corrected pseudoranges at the rover, r will be

$$R^j_r(t)_{corr} = R^j_r(t) + PRC^j(t_o) + RRC^j_B(t_o)(t - t_o) + \Delta PRC^j_{Br}(t) \quad (1.16)$$

where $\Delta PRC^j_{Br}(t)$ is a function of atmospheric variations between the base and the rover.

5.0 CONCLUSION

The paper has highlighted an approach , called a composite approach that is being studied in the effort of enhancing LADGPS accuracy. To compensate the ionospheric spatial decorrelation problem of conventional LADGPS, we have to develop a local-area ionospheric time-delay model With the model and a tropospheric time-delay model, we can modify the LADGPS correction algorithm and enhancing the positioning accuracy.

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