THE KINEMATIC POSITIONING OF VEHICLE WITH REAL-TIME DIFFERENTIAL GPS/GLONASS AND REAL-TIME KINEMATIC GPS/GLONASS

In Su Lee [a*], Kyung Chul Youn [a] , Hyun Ho Kim [a] , Woon Yong Park [b]

[a]Geo-Spatial Information Lab. Hansung Urban Information Engineering Co., Ltd
1816 Sangyuk-dong Buk-gu, DAEGU, Republic of Korea (Lee, Youn, Kim)
lis9919@hsuie.co.kr, kcyoun46@hanmail.net, hhkim@hsuie.co.kr
[b]Depart. Of Civil and Ocean Engineering, University of Dong-a, Saha-gu, Busan, Republic of Korea (Park)
uypark@daunet.donga.ac.kr

Commission II, WG II/1

KEY WORDS: GPS, GPS/GLONASS, Real-time differential positioning, Real-time kinematic positioning

ABSTRACT :

Nowadays GPS(Global Positioning System) plays a important roles in the land navigation system, but, it doesn't determine the kinematic positions of vehicles accurately because of few satellites tracked in the urban canyon covered with trees and high buildings. So GLONASS(GLObal Navigation Satellites System), the Russian satellites' system, operated in 1996, was introduced to overcome these drawbacks. So this study deals with the kinematic positioning of vehicle with Real-Time Differential Positioning using code phase and Real-Time Kinematic positioning using carrier phase. As a result, it was shown that the accuracy of the kinematic positioning of vehicle with the integrated GPS/GLONASS is better than that of GPS stand-alone by high acquisition rate of the differential corrected positions and autonomous positions.

1. PREFACE

It is essential to manage the road effectively due to the explosive increase of cars and goods. To overcome these problems through the fast acquisition and upgrade of time and positions information, the supplementary navigation systems such as GPS, INS(Inertial Navigation System), and DR(Dead Reckoning), etc are introduced. Among these navigation systems, GPS is widely used for the land navigation system. But, it is difficult to determine the kinematic positions of vehicles because of few satellites tracked in urban canyon. Especially because the positions of vehicle and the time information are required in real-time, navigation also should be performed in real-time. Between these, RDGPS(Real-Time Differential GPS)using code phase and RTK GPS(Real-Time Kinematic GPS) using carrier phase are applicable now, and its accuracies in horizontal are a few millimeters to a few centimeters. So this study deals with the RDGPS and RTK GPS to track the trajectory of vehicle with the integrated GPS/GLONASS to support the drawback of GPS in the urban canyon which can't track a few satellites.

2. GPS AND GLONASS

2.1 GPS

GPS is the radio navigation system developed by the U.S.DoD (Department of Defense). The fully operational GPS includes 24 or more active satellites approximately uniformly dispersed around six circular orbits with four or more satellites each. The orbits are inclined at an angle of 55° relative to the equator.(U.S.JPO, 1995) The orbits are approximately circular, with radii of 26,560km and orbital periods of one-half sideral day(≈11.967h). Theoretically, three or more GPS satellites will be always from most points on the earth's surface. Master control station collects the tracking data from the monitor stations and calculates the satellite orbit and clock parameter using Kalman estimation.

These results are then passed to one of the three ground control stations for eventual upload to the satellites.

2.2 GLONASS

GLONASS or GLObal Navigation Satellite System(translation from Globalnaya Navigatsionnaya Sputnikovaya Sistema), like GPS, a one-way ranging system offers users continuous worldwide three-dimensional positioning and navigation service at no cost. Developed and administrated by the Russian Military Space Forces(VKS, which is the acronym of Russian Voenno-Kosmicheski Sily) at its Department of Defense, GLONASS was not available to the civilian users until the very late 80's. Since then, GLONASS serves as a great tool to the new and existing GPS users.

Civilian users can obtain official information about the general descriptions of GLONASS from the VKR operated Coordinates Scientific Information Centre(KNITs, which is the acronym of Russian Koordinatsionnity Nauchno-Informatsionnity Tsentr) in Russia. Table 1 compares GLONASS with GPS and indicates similarities and differences.

3. GPS POSITIONING METHODS

3.1 Real-Time Differential GPS Positioning

Many applications require a several meters positioning accuracy in real-time. This high positioning accuracy is

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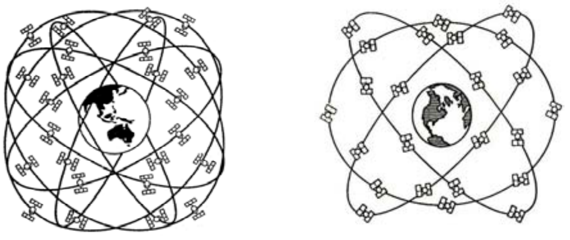
[*] In Su Lee (lis9919@hsuie.co.kr, 82-53-382-4400)

attainable through DGPS technology. In order to perform DGPS positioning in real-time, data at the reference station is transmitted to the rover using a data link in order to form the differential observations. The data link in Figure 2 may be a pair of radio transceivers[Dedes, 1994], a geostationary satellite link[Aparcio et al., 1994], a cellular phone[McCall, 1994] or FM radio[McLellan et al., 1994]. The minimum data transmission rate is 50bits per second, and the typical time latency is a few to 10 seconds[RTCM, 1994]. At the reference station, the combined effects(on a given pseudorange observation) of satellite clock error, satellite orbit error, ionospheric and trospheric delays and SA(Selective Availability) are computed from equation(1), using the known reference coordinates

$$p = \rho + c\,(d_t - d_T) + d_{ion} + d_{trop} + d_\rho + \varepsilon_P \tag{1}$$

where p is the pseudorange observation (m)
c is the light velocity ($m\cdot s^{-1}$)
ρ is the satellite-receiver geometric range (m)
d_t is the satellite clock error (m)
d_T is the receiver clock error (m)
d_{ion} is the ionospheric delay (m)
d_{trop} is the tropospheric delay (m)
d_ρ is the orbital error (m)
ε_P is the measurement noise and multipath (m)

These values, defined as pseudorange corrections, are transmitted to the rover via the data link. At the rover, the corrections are received and applied to the rover pseudorange observations, to form the single difference observations between the reference and rover receivers. Several meters positioning accuracy is achieved, depending on the reference-rover separation[Lachapelle, 1995].



(a)GPS (b) GLONASS

Figure 1. GPS and GLONASS satellites constellation

Parameter	GLONASS	GPS
Number of satellites	21 + 3 spares	21 + 3 spares
Number of orbital planes	3	6
Orbital altitude	19,100 km	20, 183 km
Inclination	64.8°	55°
Orbital period	$11^{hr}\ 15^{min}$	12^{hr}
Frequency band	L1 : (1602-1605) L2 : (1246-1256)	L1 : 1575.42 L2 : 1227.60

Table 1. The Similarities and differences of GPS and GLONASS

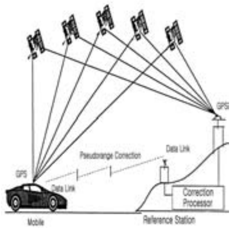


Figure 2. RDGPS

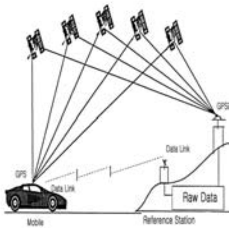


Figure 3. RTK GPS

3.2 RTK GPS Positioning

To achieve higher positioning accuracies(decimeter or centimeter level) in real-time, the double differencing technique should be implemented using carrier phase data. This requires that the raw pseudorange and carrier phase observation, or their corrections, are transmitted from the reference station to the rover using 0.5-2 seconds update rate[RTCM, 1994]. This is defined as Real-Time Kinematic (RTK) GPS positioning. (Figure 3)

Since spatial decorrelation degrades the accuracy of double difference observations, the reference-rover separation should be limited to tens of kilometers(depending on whether single or dual frequency receivers are used). The integer ambiguities can be fixed "on-the-fly"(OTF) or solved for as real numbers(float solution). Once the integer ambiguities have been fixed, centimeter level accuracies can be achieved. Alternatively, decimeter level accuracies are typically using the floating ambiguity solution.

4. TEST AND DATA ANALYSIS

4.1 Test Area

To achieve the kinematic positioning of vehicle with GPS and GLONASS, Industry complex was selected for test area. The size of test area is 0.485km, the velocity of vehicle is 40km/hr. And there are two-lane/four-lane and eight-lane road, and high building, a few electric pole, etc.

In this test, receivers(Legacy, Javad) and antennas(LegAnt, Javad) by Topcon Positioning System, Inc. was used. Figure 4 is the scene of test area. Table 2 contains the information of satellites tracked at test data. Max. 5 of 9 GLONASS satellites were tracked at that time, i.e. on November 13, 2000. and the cut-off angle was chosen as 15° .

Receiver Local time	BASE	ROVER	COMMENT
23:03:09 -23:19:16	G:2,4,7,8,11,20,31 R:1,8,15,17,22	G:2,4,7,8,11,20,31 R:1,8,17,22	RDGG
23:51:58 -23:07:13	G :1,2,4,7,11,13,20	G:1,2,4,7,8,11,13,20	RDGPS
23:29:06 -23:45:33	G:1,2,4,7,11 R:1,8,15,17,22,24	G:1,2,4,7,11,13,20 R: 1,8,17,22	RTK GG
23:13:01 -23:29:19	G:1,2,4,7,11,20,24	G:1,2,4,7,11,13,20,24	RTK GPS

Table 2. The information of satellites tracked

Figure 4. Test Area

4.2 Real-Time Differential GPS Positioning Using Code Phase

Figure 5 is the trajectory of vehicle with RDGG (Real-Time Differential GPS/GLONASS) using code phase. At the Figure, circle is the differential corrected positions and square, the autonomous positions. Specially, because there are high buildings(7-8 floors) and trees near the reference station and a data link between reference station and rover wasn't working well, corrections are not transmitted, so the kinematic positioning of vehicle is impossible. And Figure 6 is the trajectory of vehicle with the RDGPS using code phase.

Circle is the differential corrected positions, and square is the autonomous positions. RDGG is distinguished from RDGPS at course C(two-lane). This is the reason why course C is two-lane road near high buildings, so it is impossible to do the kinematic positioning of vehicle.

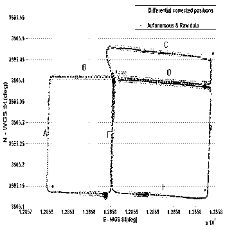


Figure 5. Trajectory by RDGG

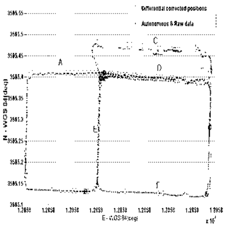


Figure 6. Trajectory by RDGPS

Table 3 contains the acquisition rate of positions by RDGG and RDGPS. The ratio of No data is 1.20%, 4.8% at RDGG and RDGPS, respectively. and the ratio of the differential corrected positions of RDGG is 10% higher than that of RDGPS.

Positioning system / Positions /epochs	RDGG	RDGPS
No data	17/1415 (1.20%)	50/1042 (4.8%)
Autonomous Positions	908/1415 (64.17%)	787/1042 (70.73%)
Differential corrected positions	490/1415 (34.63%)	205/1042 (24.7%)

Table 3. The acquisition rate of positions by RDGG and RDGPS

And To evaluate the accuracy of the horizontal components of RDGG and RDGPS observables, HDOP(Horizontal Dilution of Precision)is introduced. Table 4 contains HDOP of RDGG and RDGPS according to courses, i.e., C(two-lane), D(four-lane), E(six-lane).

The Mean HDOP of RDGG and RDGPS is 1.484 and 4.836. The RMS(Root Mean Square) of their HDOP is 0.370 and 3.094 at RDGG, RDGPS each. Through these values, the addition of GLONASS satellites has much influence on the HDOP. But, at six-lane road, the observation time of RDGG and RDGPS is separated in about an hour.

Therefore, the number of visible satellites increases. So HDOP of RDGPS is lower than that of RDGG. And Figure 7 contains HDOP of RDGG and RDGPS according to courses.

Courses / Positioning system	C	D	E
RDGG			
Mean	1.484	1.340	1.322
RMS	0.370	0.259	0.354
Number of satellites	6.184	6.906	7.187
RDGPS			
Mean	4.836	1.904	0.916
RMS	3.094	2.019	0.276
Number of satellites	3.469	6.604	9.586

Table 4. HDOP according to courses by RDGG and RDGPS

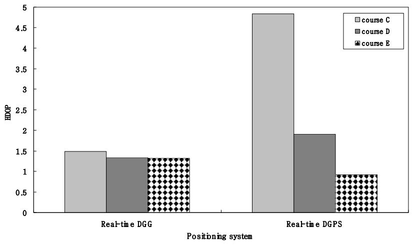


Figure 7. Mean HDOP according to courses by RDGG and RDGPS

4.3 Real-Time Kinematic GPS Positioning Using Carrier Phase

Unlike code phase, in carrier phase, the ambiguity resolution should be done fast because of influence on the positioning accuracy. There are three type-positioning solutions, i.e. the differential corrected positions, the float solutions, and the autonomous positions and raw data.

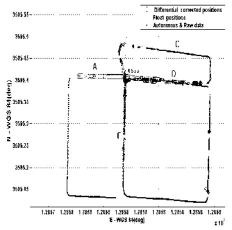


Figure 8. Trajectories by RTK GG

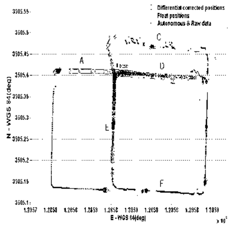


Figure 9. Trajectories by RTK GPS

Figure 8 and Figure 9 show the trajectory of vehicles with RTK GG and RTK GPS using carrier phase. At the figures, the differential corrected positions are placed near the square(i.e., reference station). Four- and six-lane road exist at this site and have good sight. But, it is impossible to take the differential corrected positions of vehicle at the rest of that sites because of few satellites tracked, multipath by the surrounding obstacles, communication jamming, etc.

But, it continues to position the vehicle constantly at course(section) C with RTK GG, whereas not so with RTK GPS. GLONASS satellites contribute to the increase of number of visible satellites required to kinematic positioning of vehicle at the urban canyon. Table 5 contains the acquisition rate of positions acquired with RTK GG and RTK GPS. At this, the ratio of the differential corrected positions with RTK GPS is two times higher than that of RTK GG, but the horizontal accuracy is lower than that of RTK GG. And Table 6 contains HDOP of course C, D, and E acquired with RTK GPS, RTK GG. In RTK GPS, at course C, D, HDOP is 3.607, 6.900 and the number of visible satellites is 2.593, 4.707, respectively. In RTK GG, at course C, D and E, HDOP is 1.087~1.447, the number of visible satellites is approximately 6. Figure 10 contains HDOP by RTK GG and RTK GPS according to courses, i.e., C, D and E.

Positioning system Positions /epochs	RTK GG	RTK GPS
No data	13/1518 (0.85%)	13/1327 (0.97%)
Autonomous positions	727/1518 47.89%)	494/1327 (37.23%)
Float positions	650/1518 (42.82%)	510/1327 (38.43%)
Differential corrected positions	127/1518 (8.4%)	288/1327(21.7%)

Table 5. The acquisition rate of positions by RTK GG and RTK GPS

Courses Positioning system	C	D	E
RTK GG			
Mean	1.447	1.087	1.089
RMS	0.408	0.349	0.497
Number of satellites	5.915	5.958	5.526
RTK GPS			
Mean	3.607	6.900	1.273
RMS	3.276	10.152	0.093
Number of satellites	2.953	4.707	5.694

Table 6. HDOP according to courses by RTK GG and RTK GPS

5. COMMENTS

5.1 True Moving Trajectory of Vehicle

Figure 10 shows the trajectory by TS(Total Station), and assumes it to be the true moving trajectory of vehicle. The trajectory of vehicle was measured apart 3~9m from the center-line of road, whereas the trajectory with TS was performed just on center-line of road.

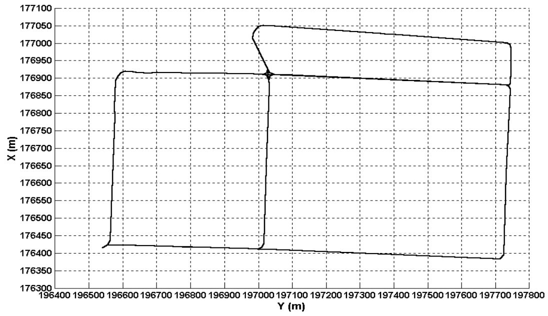


Figure 10. The trajectory with TS

5.2 The Moving Trajectory of Vehicle with Real-Time Differential Positioning

Figure. 11 shows the overlaid moving trajectory of vehicle with TS, RDGG and RDGPS based on the Cartesian Coordinates with Bessel transformed from WGS-84.

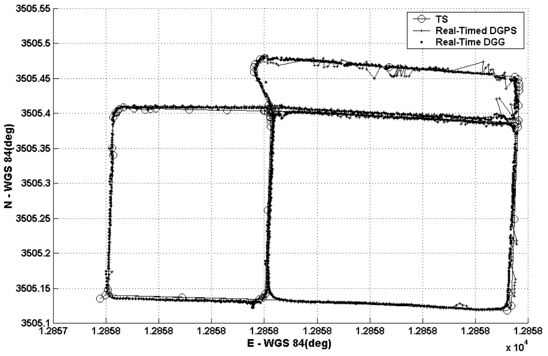


Figure 11. The overlaid trajectory by TS, RDGG and RDGPS

5.2.1 The Accuracy Evaluation of Kinematic Positioning of Vehicle with Real-Time Differential Positioning

This contains the accuracy evaluation of kinematic positioning of vehicle according to courses, i.e. A(four-lane), C(two-lane), E(six-lane), and F(eight-lane). The Mean and RMS of difference of kinematic position of vehicle between TS and RDGG, RDGPS were shown in Table 7.

Courses Positioning system	A		C		E		F	
	Mean (m)	RMS (m)	Mean (m)	RMS (m)	Mean (m)	RMS (m)	Mean (m)	RMS (m)
RDGG	0.995	0.5471	4.373	2.421	6.624	0.609	3.501	0.711
RDGPS	5.287	1.471	16.711	9.494	7.470	0.537	19.893	5.520

Table 7. The Mean and RMS of differences of kinematic positions between TS and RDGG, RDGPS

The Mean of differences of kinematic position is 0.995m and 5.287m at course A, 4.373m and 16.711m at course C in RDGG, RDGPS, respectively. Through this, there are big differences of kinematic position each other. The Mean of differences of kinematic positions between TS and RDGG, i.e., 0.995m~4.373m on course A, C, F and 6.624m on course E is within Maximum horizontal errors(10m) of digital map(position error on map : 0.2mm) by NGI(National Geographic Institute).

5.3 The Moving Trajectory of Vehicle with Real-Time Kinematic Positioning

RTK GG is possible to do the kinematic positioning of vehicle continuously with help of the high acquisition rate of data, whereas impossible in RTK GPS because of cycle slip due to the intercepting the signal of satellites.

5.3.1 The Accuracy Evaluation of Kinematic Positions of Vehicle with Real-Time Kinematic Positioning

Table 8 contains Mean and RMS of difference of kinematic positions between TS and RTK GG, RTK GPS. The Mean of differences of kinematic position is 2.470m, 4.631m, 2.424m and 3.730m, 5.922m, 6.820m at course A, C, F in RTK GG, RTK GPS, respectively. And that of course E is 9.694m, 4.314m in RTK GG, RTK GPS, respectively. The values above are within the Maximum horizontal errors(10m) of digital map(position error on map : 0.2mm) by NGI(National Geographic Institute). So it assumed to be applicable for navigation.

Courses / Positioning system	A		C		E		F	
	Mean (m)	RMS (m)	Mean (m)	RMS (m)	Mean (m)	RMS (m)	Mean (m)	RMS (m)
RTK GG	2.470	2.039	4.631	2.142	9.694	4.915	2.424	4.528
RTK GPS	3.730	1.815	5.922	2.962	4.314	2.169	6.820	5.575

Table 8. The Mean and RMS of differences of kinematic positions between TS and RTK GG, RTK GPS

6. CONCLUSION

This study deals with Real-time differential positioning and RTK positioning with the integrated GPS/GLONASS. The conclusion as follows:

1. The acquisition rate of the differential corrected positions in RDGG is 10.16% higher than that of RDGPS, and the ratio of No data in RDGG is 1.20%, but in RDGPS, that is approximately 4.8% higher and in the RDGG and RDGPS, 1.484, 4.836 at Mean and 0.370, 3.094 at RMS of HDOP. There is the reason why GLONASS satellites are integrated with GPS.

2. The total Mean of differences of kinematic positions between TS and RDGG, RDGPS is 3.873m, 12.340m, respectively. Above this, the value with RDGG is within the Maximum horizontal errors of Digital Map, but not so in RDGPS.

3.In Real-time kinematic positioning, the horizontal accuracy was shown to 10^{-1}m at the sites, which don't have obstacles such as high building, tall trees, electric poles, etc.

4. The ratio of float solutions and autonomous positions is higher than that of the differential corrected positions in RTK GG because of the difficulty of linear combination of the different GLONASS' frequency. But, it contributes to the kinematic positioning due to the high acquisition rate of data. But RTK GPS cannot perform the kinematic positioning because of the intermittent tracking of satellites respective of the high rate of differential corrected positions.

Therefore, to improve the effectiveness and accuracy of the kinematic positioning of vehicle with the integrated GPS/GLONASS, it requires the wide bandwidth of data link, the fast and accurate resolution of ambiguity, the reduction of multipath due to the surrounding obstacles, the integrated navigation system.

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