The Multipath Influence in Real-Time Kinematic of GNSS Observations at Different Antenna Heights

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Abstract

Multipath is a dominant error source in Real-Time Kinematic (RTK) applications that reduces the position, time and velocity accuracy. Mitigation of such errors can be achieved by better signal processing and antenna design. This paper attempts to examine the different height of RTK system antenna with regards to the multipath error. The results obtained in this work show height significantly changes the level of multipath in pseudorange (MP1) and multipath in the carrier phase (MP2). In our work, different antenna heights do not give the same multipath error result in the tests. The optimal height of the antenna was achieved at two meters when minimum multipath error for MP1 and MP2 was obtained. Our work experimentally proof that there is an inverse relationship between the height of the antenna and multipath with RTK algorithm .

Keywords: RTK, Antenna, Multipath GNSS, GNSS observations, OLS.

1. INTRODUCTION

Over the last decade, the number of applications that utilize Real-Time Kinematic (RTK) has steadily increased. Perhaps the most important reason of this change is the development and wide use of consumer technologies that are based on RTK Global Navigation Satellite System (GNSS).

RTK approach is a relative navigation algorithm that is a subset of differential carrier-phase positioning. RTK positioning can produce position solutions such as velocity, time and positioning in real time with high accuracy relative to the reference receiver in a clean sky environment. RTK algorithm use base station and rover station to determine coordinate.

In order to obtain centimeter accuracy from RTK system, the receiver is augmented with specialized equipment and processing techniques that can

substantially reduce or effectively eliminate most of the error that the passing signal encounters such as troposphere, ionosphere, instrumental bias, clock, multipath etc [1].

Among these error sources, the multipath effect is considered as the most dominant on accuracy problem. It happened when satellite signals enter the receiver from multiple paths and this phenomenon occurs when a reflected satellite signal is received by the receiver's antenna [2]. Multipath is a major constraint and challenging problem, because it's environmentally dependent, difficult to model mathematically, and cannot be reduced through differential positioning. But its effect is minimized by the increase in the distance between reflective objects and the receiver, where it is found that after a distance of 160 meters the multipath error becomes ignorable [3].

As far as the total multipath error effect on positioning, it has been reported that it cannot exceed five centimeters [4]; nevertheless, various methods and components have been developed over the years to minimize or eliminate the effect of the multipath error on GNSS positions which may be basically antenna-based or receiver-based technologies [5]. The receiver-based method can be categorized into two groups: the multipath estimation parameters methods (complex amplitude, time delay) and the modified the delay-locked loop (DLL) method. The first group of methods employs parameter estimation methods to resolve the multipath, an example of the latter group includes a narrow spacing correlator, strobe correlator, double delta correlator, and these methods depend on modifying the traditional DLL and improve it to be capable of mitigating multipath[6] .Antenna based methods depend on sheltering the antenna from the reflected signals other than the direct signal, examples of this kind of technique is Parabolic Antenna [7] .In this study we adopt multi linear ordinary least squares (OLS) method [8]. This method is appropriate because its displays the precise effect of different antenna heights on the multipath based on probabilistic statistical inference. Unlike other statistical methods of parameter estimation such as Maximum likelihood and Generalized Least Squares, OLS provides the precise values of the unknown parameters in the regression model and minimizes the squared errors as much as possible. This method fits into the framework of our study as we aim at observing precise relationships between different antenna heights and multipath errors. The method is popular in Real-Time Kinematic of GNSS and multipath literature as adopted by [14]. Additionally, given its robustness, OLS is a consistent estimator for the limited number of time series observations in our study. The next sections in the paper discuss methodology, results and conclusion.

2. METHODOLOGY

In this paper has been carried out an analysis of the change of multipath effect according to the antenna height. In the following discussion, we present the method used in the study.

A. Multipath estimation

Multipath error can be estimated by using a combination of carrier phase and code measurements. Multipath noise on pseudorange frequency L1 and L2 (MPL1&MPL2) in meter can be quantified by a dual frequency receiver and is given as:

$$MP_{L1} \cong \rho_{L1} - \frac{9529}{2329} . \emptyset_{L1} + \frac{7200}{2329} . \emptyset_{L2} + K_1 (1)$$

$$MP_{L2} \cong \rho_{L2} - \frac{11858}{2329} . \emptyset_{L1} + \frac{9529}{2329} . \emptyset_{L2} + K_2 (2)$$

Where ρ_{L1} and ρ_{L2} are pseudo ranges (in meters) on L1 and L2; $\emptyset_{L1}$ and $\emptyset_{L2}$ are carrier phase measurement (in meters). K_1 and K_2 are functions of unknown integer ambiguities which can be assumed constant [9].

Maximum pseudorange multipath error can reach up to (one chip wavelength) is around 293.05 meters for the C/A-code and 29.305 meters for P-code measurements.

In this work, the carrier and code measurement were collected based on equations1, 2 to calculate the values of multipath in pseudorange (MP1) and multipath in the carrier phases (MP2) which are needed for analysis.

B. Instruments and tools
- Hardware Components

Our RTK testing system is composed of two GNSS receivers OEM K706 from ComNav Company, a pair of radio transceivers 430-450 MHz, power supplies 12 volt, and two portable laptops, one laptop is used to generate the corrections from base station while another laptop is used at the rover station to generate real-time solutions and record the rover data in Receiver Independent Exchange Format (RINEX), 100 GB storage space is required for each laptop, Fig. 1 shows our setup.
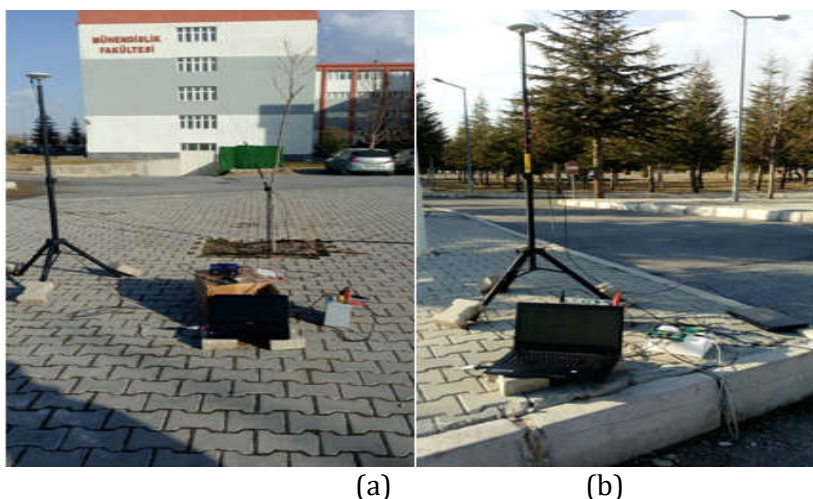

(a)   (b)

Figure 1. ComNav GNSS devices on the field (a) base station and (b) rover station

- Software component
  The following programs are used
  1. <u>CRU OEM Board Control Software</u>
     Developed by ComNav Company. This software can be used for OEM board testing, setup, data recording, data download and information display
  2. <u>TEQC software</u>
     This is a freeware program that is used to translate the recorded and stored data of the receiver from the binary receiver format to the standard RINEX format. It is also used to quality check the data before post processing and then treats the navigation and observation message as input for the estimation of the multipath values. TEQC tool is applied on the RINEX observation files, and the impact of the mitigation on the geodetic time transfer results is evaluated [10].

C. Experiment setup

OEM K706 two receiver boards were located in a fixed known coordinate. The environment was specially chosen where the receiver placed under clean sky with no near reflection objects. The distance between the two base stations is 150 meters with the knowing coordinate located at the yard of Erciyes University Faculty of Engineering- Turkey. Base station located on a single point (38:42:30.66815N 35:31:24.00092E 1080.4410) and rover station located on another single point (38:42:28.48769N 35:31:21.66004E 1080.5957). RTK corrections data was provided by the rover OEM K706 board. The rover station output was transfer using National Marine Electronics Association (NMEA) strings. The RINEX data files were retrieved from the rover K706 board and base station receiver, for four successive days the antenna was set at the same point at the same time. The observations were chosen to be at the same time in order to have the same satellite geometry, for these four days, the antenna phase centre was positioned at different heights as 2.7 meters, 2 meters, 2.5 meters, and 1.4 meters, at respective days. The RINEX files were collected in period from May 14, 2019 to May 17, 2019, in each day through time 17:25 UTC to 18:26 UTC.

The process followed to obtain the values of MP1 and MP2 is shown in the flowchart of Fig. 2, the collection of data was done on a period of one hour with an interval of five minutes resulting on twelve reading, this reading was the input to the CRU software followed by TEQC software where a processing for the data was carried out to estimate the value of MP1 and MP2 in meter.
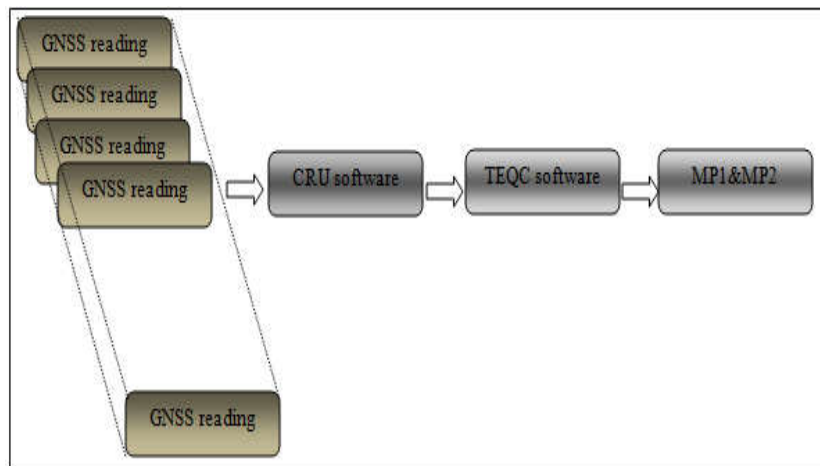
Figure 2.MP1 & MP2 calculation flow chart

3. RESULTS AND DISCUSSION

Multipath affects the pseudorange measurements and causes an error on the positioning accuracy. To verify the extent of multipath propagation effect on positioning performance, an experiment was conducted under controlled conditions. The specific location for the experiment was selected properly. During the four-day period, specific intervals were selected, and the positioning performance was analyzed in the first stage using Matlab 2018a to check the position accuracy changing with respect to multipath. The result of our experiment showed the degradation of positioning performance when multipath signals were present, which is shown in Figure 3. Besides the degradation, there is a clear deviation on the positioning accuracy values for each different antenna height.
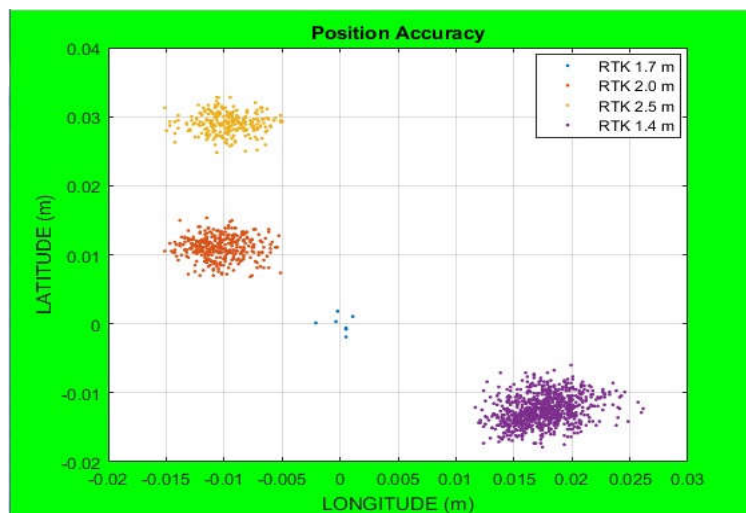

Figure3. RTK position accuracy at difference antenna heights

The second stage of our analysis was carried out using TEQC software. The output of it was a file summarizing the pseudo range and carrier

multipath residual for each satellite in each measured epoch. Table 1 presents our result in the form of a comparison of the pseudo-range and carrier phase multipath for different antenna heights.

To analysis the result of our experiment, we adopt the statistical method (OLS) that determines the best line of fit by minimizing the sum of squares residuals of heights and multipath. The method is popular for the analysis of Differential Global Position System (DGPS) field data, GPS and GNSS data processing such as [11,12], and [13]. Empirically, our estimated models take the following forms:

$$H_1 = \beta_0 + \beta_1 MP_1 + \beta_1 MP_2 + \varepsilon_1 \quad (3)$$
$$H_2 = \beta_0 + \beta_2 MP_1 + \beta_2 MP_2 + \varepsilon_2 \quad (4)$$
$$H_3 = \beta_0 + \beta_3 MP_1 + \beta_3 MP_2 + \varepsilon_3 (5)$$
$$H_4 = \beta_0 + \beta_4 MP_1 + \beta_4 MP_2 + \varepsilon_4 \quad (6)$$

Where: H_1, H_2, H_3, H_4 correspond to the four different heights models.
While β_0 & $\beta_1, \beta_2, \beta_3, \beta_4$ represent intercept and slope coefficients of the multipath, respectively. $MP_1 \ and \ MP_2$ are the first and second multipath models. The error terms ε_1--ε_4 represent the estimation errors captured in the models.

Table 1: Multipath errors in four days for RTK system using different antenna height

Observation Time	First Day		Second Day		Third Day		Fourth Day	
	Height 1 1.4m		Height 2 1.7m		Height 3 2m		Height 4 2.5m	
	MP1(m)	MP2(m)	MP1(m)	MP2(m)	MP1(m)	MP2(m)	MP1(m)	MP2(m)
17:25 -17:30	0.111258	0.302468	2.515344	0.356789	0.115788	0.331195	0.122222	0.276744
17:30 -17:35	0.100648	0.267125	1.434332	0.379477	0.110023	0.293884	0.111740	0.321143
17:35 -17:40	0.105575	0.259784	0.531952	0.319052	0.102225	0.290255	0.118542	0.310683
17:40 -17:45	0.097605	0.240602	1.409393	0.327192	0.115552	0.269698	0.103743	0.251685
17:45-17:50	0.107223	0.299489	2.516366	0.317467	0.108297	0.210441	0.102142	0.213505
17:50-17:55	0.079104	0.263285	3.833304	0.277228	0.114000	0.248413	0.119855	0.233428
17:55-18:00	0.102369	0.252154	5.206226	0.349249	0.095128	0.254013	0.111740	0.220421
18:00-18:05	0.122702	0.255364	0.144456	0.295245	0.102884	0.225223	0.101741	0.233413
18:05-18:10	0.117544	0.199580	0.123783	0.201638	0.089188	0.257852	0.111902	0.223204
18:10-18:15	0.119877	0.253896	0.137315	0.247921	0.184226	0.218989	0.111741	0.233427
18:15 18:20	0.118506	0.315681	0.121787	0.251350	0.118403	0.233009	0.114322	0.236095
18:20-18:25	0.103226	0.265753	0.124679	0.243561	0.129549	0.262004	0.113740	0.220429

Table 2 depicts the summary of the descriptive statistics for our data. All the observations were accurately recorded. There is no strong deviation within the data, and the data appears to be normally spread. The data was therefore appropriate for statistical analysis under the OLS framework.

Table 2: Descriptive Statistics

	Height 1 1.4m		Height 2 1.7m		Height 3 2m		Height 4 2.5m	
	MP1(m)	MP1(m)	MP1(m)	MP2(m)	MP1(m)	MP2(m)	MP1(m)	MP2(m)
Mean	0.107136	0.264598	1.508245	0.297181	0.115439	0.257915	0.111953	0.247848
Median	0.106399	0.261535	0.970673	0.306356	0.112012	0.255933	0.111821	0.233428
Maximum	0.122702	0.315681	5.206226	0.379477	0.184226	0.331195	0.122222	0.321143
Minimum	0.079104	0.199580	0.121787	0.201638	0.089188	0.210441	0.101741	0.213505
Std. Dev.	0.012130	0.030824	1.694175	0.053733	0.024226	0.034940	0.006662	0.035959
Observations	12	12	12	12	12	12	12	12

Source: Authors' estimations

Table 3. Shows the results from the estimation of equations 2-6. Statistical level of significance and levels of precision (accuracy) of the estimated parameters are indicated by the values of probabilities (prob.) and standard errors (s.e.), respectively. The results for the first height (1.4m, equation 3), show that multipath errors 1 and 2 both reduce. Although, the reduction in MP1 is statistically significant at 95%, the reduction in MP2 is statistically insignificant because its probability index is below 95%level of significance. Our results for this model are accurate as indicated by the standard errors.

The estimated parameters for the second height (1.7m, equation 4) indicate that MP2 reduces significantly, while MP1 increases. However, the increase in MP1 is not statistically supported because its probability statistic is below the 95% level of significance. The parameters of the third 3 model (height 2, equation 5) are both negative and statistically significant with plausible levels of accuracy. This implies that both MP1 and MP2 significantly decrease at the height of 2 meters. Finally, we obtained negative MP1 and MP2 parameters from the estimation of model 6 (at 2.5m). It should be, however, noted that parameter estimate for MP2 was statistically insignificant. From our results, we observe that the more we increase the height, the further we record significant reduction in both multipath errors 1 & 2. Although the reduction in multipath is insignificant in some models, the general observation is that higher antenna heights significantly reduce the levels of multipath errors. For example, the MP1 parameter is significant in all the four equations (3-6) except equation 3. This implies that the more we increase the height (from 1.4 to 1.7, then to 2 & finally to 2.5), the more we reduce the level of multipath errors. Similar observations are recorded for MP2 although two observations were insignificant. The results of the third model (equation 5) are unique because the parameters are both negative and highly significant. This implies that at the height of 2 meters, both MP1 and MP2 reduce significantly. This basically suggests that 2 meters could be the optimal height for both MP1 and MP2. This is because it's at this height (2m) that we obtain significantly negative parameter estimates for the two

multipath errors.

Table 3.OLSestimates of the effect of different heights on Mp1 and Mp2

	1.4m	**1.7m**	**2m**	**2.5m**
MP1	-2.87	6.66	-9.57	-2.87
S.e	(9.87)	(4.18)	(4.20)	1.03
Prob	0.0279	0.1457	0.0487	0.0173
MP2	-8.50	-3.92	-7.10	7.22
S.e	(6.11)	(1.32)	(2.91)	(1.83)
Prob	0.1975	0.0156	0.0374	0.7021

Source: Authors' estimations. Notes: S.e and Prob. represent standard error and probability respectively.

4. CONCULUSIONS

Differences in antenna height were detected and verified to minimize pseudo-multipath paths RTK. The OLS estimates for the four different models suggest that marginal increase in height significantly reduces both multipath MP1 & MP2. Multipath signals increase the potential error values for position accuracy and it's evident that the optimal height for positioning the RTK GNSS antenna in order to reduce pseudo range multipath is at the lowest level.

Acknowledgements

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